

CARNEGIE INSTITUTION OF WASHINGTON

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CARNEGIE INSTITUTION OF WASHINGTON

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CARNEGIE INSTITUTION OF WASHINGTON
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1947

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PRESIDENT AND TRUSTEES

PRESIDENT

VANNEVAR BUSH

BOARD OF TRUSTEES

WALTER S. GIFFORD, *Chairman*
ELIHU ROOT, JR., *Vice-Chairman*
LEWIS H. WEED, *Secretary*

JAMES F. BELL
ROBERT WOODS BLISS
LINDSAY BRADFORD
FREDERIC A. DELANO
HOMER L. FERGUSON
W. CAMERON FORBES
WALTER S. GIFFORD
HERBERT HOOVER

FRANK B. JEWETT
ERNEST O. LAWRENCE
ALFRED L. LOOMIS
ROSWELL MILLER
HENRY S. MORGAN
SEELEY G. MUDD
HENNING W. PRENTIS, JR.
GORDON S. RENTSCHLER

ELIHU ROOT, JR.
HENRY R. SHEPLEY
RICHARD P. STRONG
CHARLES P. TAFT
JUAN T. TRIPPE
JAMES W. WADSWORTH
FREDERIC C. WALCOTT
LEWIS H. WEED

Executive Committee

ROBERT WOODS BLISS
VANNEVAR BUSH

WALTER S. GIFFORD, *Chairman*
GORDON S. RENTSCHLER
ELIHU ROOT, JR.
HENRY R. SHEPLEY

FREDERIC C. WALCOTT
LEWIS H. WEED

Finance Committee

ALFRED L. LOOMIS

LINDSAY BRADFORD, *Chairman*
HENRY S. MORGAN
HENNING W. PRENTIS, JR.

ELIHU ROOT, JR.

Auditing Committee

HOMER L. FERGUSON

FREDERIC A. DELANO, *Chairman*

JAMES W. WADSWORTH

Nominating Committee

WALTER S. GIFFORD

FRANK B. JEWETT, *Chairman*
HENRY S. MORGAN

HENNING W. PRENTIS, JR.

STANDING COMMITTEES

Committee on Astronomy

ROSWELL MILLER

SEELEY G. MUDD, *Chairman*
ELIHU ROOT, JR.

JUAN T. TRIPPE

Committee on Terrestrial Sciences

HOMER L. FERGUSON

FRANK B. JEWETT, *Chairman*
ERNEST O. LAWRENCE

FREDERIC C. WALCOTT

Committee on Biological Sciences

JAMES F. BELL

LEWIS H. WEED, *Chairman*
ALFRED L. LOOMIS
HENNING W. PRENTIS, JR.

RICHARD P. STRONG

Committee on Historical Research

ROBERT WOODS BLISS

HENRY R. SHEPLEY, *Chairman*
RICHARD P. STRONG
CHARLES P. TAFT

JAMES W. WADSWORTH

BIOLOGICAL SCIENCES

DIVISION OF PLANT BIOLOGY

Central Laboratory, Stanford, California

Desert Laboratory, opened in 1903, became headquarters of Department of Botanical Research in 1905. Name changed to Laboratory for Plant Physiology in 1923; reorganized in 1928 as Division of Plant Biology, including Ecology. Herman A. Spoehr, Chairman 1927-1930 and 1931-1947.

C. STACY FRENCH, *Director*
JENS C. CLAUSEN
WILLIAM M. HIESEY
DAVID D. KECK

HAROLD W. MILNER
JAMES H. C. SMITH
HERMAN A. SPOEHR
HAROLD H. STRAIN

DEPARTMENT OF EMBRYOLOGY

Wolfe and Madison Streets, Baltimore 5, Maryland

Organized in 1914; Franklin P. Mall, Director 1914-1917; George L. Streeter, Director 1918-1940

GEORGE W. CORNER, *Director*
ROBERT K. BURNS
LOUIS B. FLEXNER
CHESTER H. HEUSER, *Curator of the Embryological Collection*

SAMUEL R. M. REYNOLDS
DAVID B. TYLER
†WALTER S. WILDE

DEPARTMENT OF GENETICS

Cold Spring Harbor, Long Island, New York

Station for Experimental Evolution, opened in 1904, combined with Eugenics Record Office in 1921 to form Department of Genetics. Charles B. Davenport, Director 1904-1934; Albert F. Blakeslee, Director 1935-1941.

MILISLAV DEMEREC, *Director*
BERWIND P. KAUFMANN
EDWIN C. MACDOWELL
BARBARA MCCLINTOCK
MARGARET R. McDONALD

Research Associates
ERNEST W. CASPARI
†HOWARD B. NEWCOMBE

HISTORICAL RESEARCH

DIVISION OF HISTORICAL RESEARCH

10 Frisbie Place, Cambridge 38, Massachusetts

Department of Historical Research organized in 1903; Andrew C. McLaughlin, Director 1903-1905; J. Franklin Jameson, Director 1905-1928. In 1930 this Department was incorporated as a section of United States history in a new Division of Historical Research.

ALFRED V. KIDDER, *Chairman*
†ROBERT S. CHAMBERLAIN
MARGARET W. HARRISON, *Editor*
SYLVANUS G. MORLEY
EARL H. MORRIS
ALEXANDER POGO
HARRY E. D. POLLOCK
TATIANA PROSKOURIAKOFF
RALPH L. ROYS

KARL RUPPERT
GEORGE SARTON
ANNA O. SHEPARD
EDWIN M. SHOOK
A. LEDYARD SMITH
ROBERT E. SMITH
GUSTAV STRÖMSVIK
J. ERIC S. THOMPSON
†ALFONSO VILLA R.

† Resigned in 1947.

RESEARCH ASSOCIATES

RESEARCH ASSOCIATES ENGAGED IN POST-RETIREMENT STUDIES

WALTER S. ADAMS, Astronomy

HERBERT E. MERWIN, Geophysics

GEORGE L. STREETER, Embryology

RESEARCH ASSOCIATES CONNECTED WITH OTHER INSTITUTIONS

V. BJERKNES (University of Oslo), Meteorology

JOSEPH C. BOYCE (New York University), Physics

RALPH W. CHANEY (University of California), Paleobotany

TH. DOBZHANSKY (Columbia University) Genetics

JOSEPH GILLMAN (Johannesburg Medical School), Embryology

FRANK T. GUCKER, JR. (Indiana University), Chemistry

ROSS G. HARRISON (Yale University), Biology

ARTHUR T. HERTIG (Boston Lying-in Hospital), Embryology

E. A. LOWE (The Institute for Advanced Study), Paleogeography

ROBERT REDFIELD (University of Chicago), Anthropology

FRANCE V. SCHOLES (University of New Mexico), History

JOEL STEBBINS (University of Wisconsin), Astronomy

SOL TAX (University of Chicago), Ethnology

OFFICES OF ADMINISTRATION

Office of the President

VANNEVAR BUSH, *President*
PAUL A. SCHERER, *Executive Officer*
SAMUEL CALLAWAY, *President's Secretary*

Office of Publications and Public Relations

FREDERICK G. FASSETT, JR., *Director*
AILENE J. BAUER, *Assistant to the Director*
DOROTHY R. SWIFT, *Editor*

Adviser on International Scientific Relations

JOHN A. FLEMING

Office of the Bursar

EARLE B. BIESECKER, *Bursar*
J. STANLEY LINGEBACH, *Assistant Bursar*
JAMES F. SULLIVAN, *Assistant to the Bursar*

Investment Office (New York City)

PARKER MONROE, *Investment Officer*
RICHARD F. F. NICHOLS, *Assistant Investment Officer*

ORGANIZATION, PLAN, AND SCOPE

The Carnegie Institution of Washington was founded by Andrew Carnegie, January 28, 1902, when he gave to a board of trustees an endowment of registered bonds of the par value of ten million dollars. To this fund an addition of two million dollars was made by Mr. Carnegie on December 10, 1907, and a further addition of ten million dollars was made by him on January 19, 1911. Furthermore, the income of a reserve fund of about three million dollars, accumulated in accordance with the founder's specifications in 1911, is now available for general use, and in recent years a total of ten million dollars has been paid by the Carnegie Corporation of New York as increase to the Endowment Fund of the Institution. The Institution was originally organized under the laws of the District of Columbia and incorporated as the *Carnegie Institution*, articles of incorporation having been executed on January 4, 1902. The Institution was reincorporated, however, by an act of the Congress of the United States, approved April 28, 1904, under the title of the *Carnegie Institution of Washington*. (See existing Articles of Incorporation on following pages.)

Organization under the new Articles of Incorporation was effected May 18, 1904, and the Institution was placed under the control of a board of twenty-four trustees, all of whom had been members of the original corporation. The trustees meet annually in December to consider the affairs of the Institution in general, the progress of work already undertaken, and the initiation of new projects, and to make the necessary appropriations for the ensuing year. During the intervals between the meetings of the trustees the affairs of the Institution are conducted by an Executive Committee chosen by and from the Board of Trustees and acting through the President of the Institution as chief executive officer.

The Articles of Incorporation of the Institution declare in general "that the objects of the corporation shall be to encourage, in the broadest and most liberal manner, investigation, research, and discovery, and the application of knowledge to the improvement of mankind."

The Institution is essentially an operating organization. It attempts to advance fundamental research in fields not normally covered by the activities of other agencies, and to concentrate its attention upon specific problems, with the idea of shifting attack from time to time to meet the more pressing needs of research as they develop with increase of knowledge. Some of these problems require the collaboration of several investigators, special equipment, and continuous effort. Many close relations exist among activities of the Institution, and a type of organization representing investigations in astronomy, in terrestrial sciences, in biological sciences, and in historical research has been effected. Conference groups on various subjects have played a part in bringing new vision and new methods to bear upon many problems. Constant efforts are made to facilitate interpretation and application of results of research activities of the Institution, and an Office of Publications and Public Relations provides means for appropriate publication.

ARTICLES OF INCORPORATION

PUBLIC No. 260. An Act to incorporate the Carnegie Institution of Washington.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the persons following being persons who are now trustees of the Carnegie Institution, namely, Alexander Agassiz, John S. Billings, John L. Cadwalader, Cleveland H. Dodge, William N. Frew, Lyman J. Gage, Daniel C. Gilman, John Hay, Henry L. Higginson, William Wirt Howe, Charles L. Hutchinson, Samuel P. Langley, William Lindsay, Seth Low, Wayne MacVeagh, Darius O. Mills, S. Weir Mitchell, William W. Morrow, Ethan A. Hitchcock, Elihu Root, John C. Spooner, Andrew D. White, Charles D. Walcott, Carroll D. Wright, their associates and successors duly chosen, are hereby incorporated and declared to be a body corporate by the name of the Carnegie Institution of Washington and by that name shall be known and have perpetual succession, with the powers, limitations, and restrictions herein contained.

SEC. 2. That the objects of the corporation shall be to encourage, in the broadest and most liberal manner, investigation, research, and discovery, and the application of knowledge to the improvement of mankind; and in particular—

(a) To conduct, endow, and assist investigation in any department of science, literature, or art, and to this end to cooperate with governments, universities, colleges, technical schools, learned societies, and individuals.

(b) To appoint committees of experts to direct special lines of research.

(c) To publish and distribute documents.

(d) To conduct lectures, hold meetings, and acquire and maintain a library.

(e) To purchase such property, real or personal, and construct such building or buildings as may be necessary to carry on the work of the corporation.

(f) In general, to do and perform all things necessary to promote the objects of the institution, with full power, however, to the trustees hereinafter appointed and their successors from time to time to modify the conditions and regulations under which the work shall be carried on, so as to secure the application of the funds in the manner best adapted to the conditions of the time, provided that the objects of the corporation shall at all times be among the foregoing or kindred thereto.

SEC. 3. That the direction and management of the affairs of the corporation and the control and disposal of its property and funds shall be vested in a board of trustees, twenty-two in number, to be composed of the following individuals: Alexander Agassiz, John S. Billings, John L. Cadwalader, Cleveland H. Dodge, William N. Frew, Lyman J. Gage, Daniel C. Gilman, John Hay, Henry L. Higginson, William Wirt Howe, Charles L. Hutchinson, *Samuel P. Langley*, William Lindsay, Seth Low, Wayne MacVeagh, Darius O. Mills, S. Weir Mitchell, William W. Morrow, *Ethan A. Hitchcock*, Elihu Root, John C. Spooner, Andrew D. White, Charles D. Walcott, Carroll D. Wright, who shall constitute the first board of trustees. The board of trustees shall have power from time to time to increase its membership to not more than twenty-seven members. Vacancies occasioned by death, resignation, or otherwise shall be filled by the remaining trustees in such manner as the by-laws

ARTICLES OF INCORPORATION

shall prescribe; and the persons so elected shall thereupon become trustees and also members of the said corporation. The principal place of business of the said corporation shall be the city of Washington, in the District of Columbia.

SEC. 4. That such board of trustees shall be entitled to take, hold, and administer the securities, funds, and property so transferred by said Andrew Carnegie to the trustees of the Carnegie Institution and such other funds or property as may at any time be given, devised, or bequeathed to them, or to such corporation, for the purposes of the trust; and with full power from time to time to adopt a common seal, to appoint such officers, members of the board of trustees or otherwise, and such employees as may be deemed necessary in carrying on the business of the corporation, at such salaries or with such remuneration as they may deem proper; and with full power to adopt by-laws from time to time and such rules or regulations as may be necessary to secure the safe and convenient transaction of the business of the corporation; and with full power and discretion to deal with and expend the income of the corporation in such manner as in their judgment will best promote the objects herein set forth and in general to have and use all powers and authority necessary to promote such objects and carry out the purposes of the donor. The said trustees shall have further power from time to time to hold as investments the securities hereinafter referred to so transferred by Andrew Carnegie, and any property which has been or may be transferred to them or such corporation by Andrew Carnegie or by any other person, persons, or corporation, and to invest any sums or amounts from time to time in such securities and in such form and manner as are permitted to trustees or to charitable or literary corporations for investment, according to the laws of the States of New York, Pennsylvania, or Massachusetts, or in such securities as are authorized for investment by the said deed of trust so executed by Andrew Carnegie, or by any deed of gift or last will and testament to be hereafter made or executed.

SEC. 5. That the said corporation may take and hold any additional donations, grants, devises, or bequests which may be made in further support of the purposes of the said corporation, and may include in the expenses thereof the personal expenses which the trustees may incur in attending meetings or otherwise in carrying out the business of the trust, but the services of the trustees as such shall be gratuitous.

SEC. 6. That as soon as may be possible after the passage of this Act a meeting of the trustees hereinbefore named shall be called by Daniel C. Gilman, John S. Billings, Charles D. Walcott, S^r Weir Mitchell, John Hay, Elihu Root, and Carroll D. Wright, or any four of them, at the city of Washington, in the District of Columbia, by notice served in person or by mail addressed to each trustee at his place of residence; and the said trustees, or a majority thereof, being assembled, shall organize and proceed to adopt by-laws, to elect officers and appoint committees, and generally to organize the said corporation; and said trustees herein named, on behalf of the corporation hereby incorporated, shall thereupon receive, take over, and enter into possession, custody, and management of all property, real or personal, of the corporation heretofore known as the Carnegie Institution, incorporated, as hereinbefore set forth under "An Act to establish a Code of Law for the District of Columbia, January fourth, nineteen hundred and two," and to all its rights, contracts, claims, and property of any kind or nature; and the several officers of such corporation, or

CARNEGIE INSTITUTION OF WASHINGTON

any other person having charge of any of the securities, funds, real or personal, books, or property thereof, shall, on demand, deliver the same to the said trustees appointed by this Act or to the persons appointed by them to receive the same; and the trustees of the existing corporation and the trustees herein named shall and may take such other steps as shall be necessary to carry out the purposes of this Act.

SEC. 7. That the rights of the creditors of the said existing corporation known as the Carnegie Institution shall not in any manner be impaired by the passage of this Act, or the transfer of the property hereinbefore mentioned, nor shall any liability or obligation for the payment of any sums due or to become due, or any claim or demand, in any manner or for any cause existing against the said existing corporation, be released or impaired; but such corporation hereby incorporated is declared to succeed to the obligations and liabilities and to be held liable to pay and discharge all of the debts, liabilities, and contracts of the said corporation so existing to the same effect as if such new corporation had itself incurred the obligation or liability to pay such debt or damages, and no such action or proceeding before any court or tribunal shall be deemed to have abated or been discontinued by reason of the passage of this Act.

SEC. 8. That Congress may from time to time alter, repeal, or modify this Act of incorporation, but no contract or individual right made or acquired shall thereby be divested or impaired.

SEC. 9. That this Act shall take effect immediately.

Approved, April 28, 1904

BY-LAWS OF THE INSTITUTION

Adopted December 13, 1904. Amended December 13, 1910, December 13, 1912, December 10, 1937, December 15, 1939, December 13, 1940, December 18, 1942, and December 12, 1947

ARTICLE I

THE TRUSTEES

1. The Board of Trustees shall consist of twenty-four members, with power to increase its membership to not more than twenty-seven members. The Trustees shall hold office continuously and not for a stated term.
2. In case any Trustee shall fail to attend three successive annual meetings of the Board he shall thereupon cease to be a Trustee.
3. No Trustee shall receive any compensation for his services as such.
4. All vacancies in the Board of Trustees shall be filled by the Trustees by ballot at an annual meeting, but no person shall be declared elected unless he receives the votes of two-thirds of the Trustees present.

ARTICLE II

OFFICERS OF THE BOARD

1. The officers of the Board shall be a Chairman of the Board, a Vice-Chairman, and a Secretary, who shall be elected by the Trustees, from the members of the Board, by ballot to serve for a term of three years. All vacancies shall be filled by the Board for the unexpired term; provided, however, that the Executive Committee shall have power to fill a vacancy in the office of Secretary to serve until the next meeting of the Board of Trustees.
2. The Chairman shall preside at all meetings and shall have the usual powers of a presiding officer.
3. The Vice-Chairman, in the absence or disability of the Chairman, shall perform the duties of the Chairman.
4. The Secretary shall issue notices of meetings of the Board, record its transactions, and conduct that part of the correspondence relating to the Board and to his duties.

ARTICLE III

EXECUTIVE ADMINISTRATION

The President

1. There shall be a President who shall be elected by ballot by, and hold office during the pleasure of, the Board, who shall be the chief executive officer of the Institution. The President, subject to the control of the Board and the Executive Committee, shall have general charge of all matters of administration and supervision of all arrangements for research and other work undertaken by the Institution or with its funds. He shall prepare and submit to the Board of Trustees and to the Executive

CARNEGIE INSTITUTION OF WASHINGTON

Committee plans and suggestions for the work of the Institution, shall conduct its general correspondence and the correspondence with applicants for grants and with the special advisers of the Committee, and shall present his recommendations in each case to the Executive Committee for decision. All proposals and requests for grants shall be referred to the President for consideration and report. He shall have power to remove, appoint, and, within the scope of funds made available by the Trustees, provide for compensation of subordinate employees and to fix the compensation of such employees within the limits of a maximum rate of compensation to be established from time to time by the Executive Committee. He shall be *ex officio* a member of the Executive Committee.

2. He shall be the legal custodian of the seal and of all property of the Institution whose custody is not otherwise provided for. He shall sign and execute on behalf of the corporation all contracts and instruments necessary in authorized administrative and research matters and affix the corporate seal thereto when necessary, and may delegate the performance of such acts and other administrative duties in his absence to the Executive Officer. He may execute all other contracts, deeds, and instruments on behalf of the corporation and affix the seal thereto when expressly authorized by the Board of Trustees or Executive Committee. He may, within the limits of his own authorization, delegate to the Executive Officer authority to act as custodian of and affix the corporate seal. He shall be responsible for the expenditure and disbursement of all funds of the Institution in accordance with the directions of the Board and of the Executive Committee, and shall keep accurate accounts of all receipts and disbursements. Following approval by the Executive Committee he shall transmit to the Board of Trustees before its annual meeting in December a written report of the operations and business of the Institution for the preceding fiscal year with his recommendations for work and appropriations for the succeeding calendar year.

3. He shall attend all meetings of the Board of Trustees.

4. There shall be an officer designated Executive Officer who shall be appointed by and hold office at the pleasure of the President, subject to the approval of the Executive Committee. His duties shall be to assist and act for the President as the latter may duly authorize and direct.

5. The President shall retire from office at the end of the calendar year in which he becomes sixty-five years of age.

ARTICLE IV

MEETINGS

1. The annual meeting of the Board of Trustees shall be held in the City of Washington, in the District of Columbia, on the first Friday following the second Thursday of December in each year unless the date and place of meeting are otherwise ordered by the Executive Committee.

2. Special meetings of the Board may be called by the Executive Committee by notice served personally upon, or mailed to the usual address of, each Trustee twenty days prior to the meeting.

3. Special meetings shall, moreover, be called in the same manner by the Chairman upon the written request of seven members of the Board.

BY-LAWS OF THE INSTITUTION

ARTICLE V

COMMITTEES

1. There shall be the following standing Committees, *viz.* an Executive Committee, a Finance Committee, an Auditing Committee, and a Nominating Committee.

2. All vacancies occurring in the Executive Committee, the Finance Committee, the Auditing Committee, and the Nominating Committee shall be filled by the Trustees at the next regular meeting. In case of vacancy in the Finance Committee, the Auditing Committee, or the Nominating Committee, upon request of the remaining members of such committee, the Executive Committee may fill such vacancy by appointment until the next meeting of the Board of Trustees.

3. The terms of all officers and of all members of committees, as provided for herein, shall continue until their successors are elected or appointed.

Executive Committee

4. The Executive Committee shall consist of the Chairman and Secretary of the Board of Trustees and the President of the Institution *ex officio* and, in addition, five trustees to be elected by the Board by ballot for a term of three years, who shall be eligible for re-election. Any member elected to fill a vacancy shall serve for the remainder of his predecessor's term.

5. The Executive Committee shall, when the Board is not in session and has not given specific directions, have general control of the administration of the affairs of the corporation and general supervision of all arrangements for administration, research, and other matters undertaken or promoted by the Institution. It shall also submit to the Board of Trustees a printed or typewritten report of each of its meetings, and at the annual meeting shall submit to the Board a report for publication.

6. The Executive Committee shall have power to authorize the purchase, sale, exchange, or transfer of real estate.

Finance Committee

7. The Finance Committee shall consist of five members to be elected by the Board of Trustees by ballot for a term of three years.

8. The Finance Committee shall have custody of the securities of the corporation and general charge of its investments and invested funds, and shall care for and dispose of the same subject to the directions of the Board of Trustees. It shall have power to authorize the purchase, sale, exchange, or transfer of securities and to delegate this power. It shall consider and recommend to the Board from time to time such measures as in its opinion will promote the financial interests of the Institution, and shall make a report at each meeting of the Board.

Auditing Committee

9. The Auditing Committee shall consist of three members to be elected by the Board of Trustees by ballot for a term of three years.

CARNEGIE INSTITUTION OF WASHINGTON

10. Before each annual meeting of the Board of Trustees, the Auditing Committee shall cause the accounts of the Institution for the preceding fiscal year to be audited by public accountants. The accountants shall report to the Committee, and the Committee shall present said report at the ensuing annual meeting of the Board with such recommendations as the Committee may deem appropriate.

Nominating Committee

11. The Nominating Committee shall consist of the Chairman of the Board of Trustees *ex officio* and, in addition, three trustees to be elected by the Board by ballot for a term of three years, who shall not be eligible for re-election until after the lapse of one year. Any member elected to fill a vacancy shall serve for the remainder of his predecessor's term, provided that of the Nominating Committee first elected after adoption of this By-Law one member shall serve for one year, one member shall serve for two years, and one member shall serve for three years, the Committee to determine the respective terms by lot.

12. Sixty days prior to an annual meeting of the Board the Nominating Committee shall notify the Trustees by mail of the vacancies to be filled in membership of the Board. Each Trustee may submit nominations for such vacancies. Nominations so submitted shall be considered by the Nominating Committee, and ten days prior to the annual meeting the Nominating Committee shall submit to members of the Board by mail a list of the persons so nominated, with its recommendations for filling existing vacancies on the Board and its Standing Committees. No other nominations shall be received by the Board at the annual meeting except with the unanimous consent of the Trustees present.

ARTICLE VI

FINANCIAL ADMINISTRATION

1. No expenditure shall be authorized or made except in pursuance of a previous appropriation by the Board of Trustees, or as provided in Article V, paragraph 8, hereof.

2. The fiscal year of the Institution shall commence on the first day of July in each year.

3. The Executive Committee shall submit to the annual meeting of the Board a full statement of the finances and work of the Institution for the preceding fiscal year and a detailed estimate of the expenditures of the succeeding calendar year.

4. The Board of Trustees, at the annual meeting in each year, shall make general appropriations for the ensuing calendar year; but nothing contained herein shall prevent the Board of Trustees from making special appropriations at any meeting.

5. The Executive Committee shall have general charge and control of all appropriations made by the Board. Following the annual meeting each year, the Executive Committee may make allotment of funds for the period from January 1 to termination of the fiscal year on June 30. It may also make allotment of funds for the period from July 1 to December 31 in advance of July 1. The Committee shall, however, have full authority for allotment of available funds to meet necessary

BY-LAWS OF THE INSTITUTION

expenditures by other methods, if desirable, and for transfer of balances to meet special needs. It shall make provision for outstanding obligations and for reversion of unexpended balances at termination of the fiscal year.

6. The securities of the Institution and evidences of property, and funds invested and to be invested, shall be deposited in such safe depository or in the custody of such trust company and under such safeguards as the Finance Committee shall designate, subject to directions of the Board of Trustees. Income of the Institution available for expenditure shall be deposited in such banks or depositories as may from time to time be designated by the Executive Committee.

7. Any trust company entrusted with the custody of securities by the Finance Committee may, by resolution of the Board of Trustees, be made Fiscal Agent of the Institution, upon an agreed compensation, for the transaction of the business coming within the authority of the Finance Committee.

ARTICLE VII

AMENDMENT OF BY-LAWS

1. These by-laws may be amended at any annual or special meeting of the Board of Trustees by a two-thirds vote of the members present, provided written notice of the proposed amendment shall have been served personally upon, or mailed to the usual address of, each member of the Board twenty days prior to the meeting.

ABSTRACT OF MINUTES OF THE FORTY-NINTH MEETING OF THE BOARD OF TRUSTEES

The meeting was held in Washington, D. C., in the Board Room of the Administration Building, on Friday, December 12, 1947. It was called to order at 10:30 A.M. by the Chairman, Mr. Gifford.

Upon roll call, the following Trustees responded: James F. Bell, Robert Woods Bliss, Lindsay Bradford, Frederic A. Delano, Homer L. Ferguson, W. Cameron Forbes, Walter S. Gifford, Frank B. Jewett, Ernest O. Lawrence, Alfred L. Loomis, Roswell Miller, Henry S. Morgan, Seeley G. Mudd, Henning W. Prentis, Jr., Gordon S. Rentschler, Elihu Root, Jr., Henry R. Shepley, Juan T. Trippe, James W. Wadsworth, and Lewis H. Weed. The President of the Institution, Vannevar Bush, was also in attendance.

The minutes of the forty-eighth meeting were approved as printed and submitted to the members of the Board.

Reports of the President, the Executive Committee, the Auditor, the Finance Committee, the Auditing Committee, and of the Chairmen of Divisions, Directors of Departments, and Research Associates of the Institution were presented and considered.

The following appropriations for the year 1948 were authorized:

Pension Fund	\$95,000
Administration (including expenses of Investment Office and of insurance)	115,800
Expenses of Office of Publications and Public Relations	34,400
Departmental Research Operations	1,113,460
	\$1,358,660

Lewis H. Weed was elected as Secretary of the Board for the unexpired term ending in 1948. Frederic C. Walcott was re-elected to continue service as a member of the Executive Committee for the ensuing three-year term, Gordon S. Rentschler was elected a member of the Executive Committee for the ensuing three-year term, and Elihu Root, Jr. was elected a member of the Executive Committee for the unexpired term ending in 1948. Lindsay Bradford and Henning W. Prentis, Jr. were re-elected to continue service as members of the Finance Committee for the ensuing three-year term, and Alfred L. Loomis was elected a member of the Finance Committee for the unexpired term ending in 1948.

Amendments to the By-Laws of the Institution recommended by the Executive Committee were adopted. A Nominating Committee provided by the amended By-Laws was organized with Walter S. Gifford as *ex-officio* member and by the election of Frank B. Jewett for the one-year term, Henry S. Morgan for the two-year term, and Henning W. Prentis, Jr. for the three-year term. Frank B. Jewett was chosen as Chairman of the Nominating Committee.

A plan of unified operation of the Mount Wilson and Palomar Observatories was considered and approved in principle.

The meeting adjourned at 12:10 P.M.

REPORT OF THE EXECUTIVE COMMITTEE

FOR THE YEAR ENDING OCTOBER 31, 1947

To the Trustees of the Carnegie Institution of Washington:

GENTLEMEN: Article V, section 3 of the By-Laws provides that the Executive Committee shall submit, at the annual meeting of the Board of Trustees, a report for publication; and Article VI, section 3 provides that the Executive Committee shall also submit, at the same time, a full statement of the finances and work of the Institution and a detailed estimate of the expenditures for the succeeding year. In accordance with these provisions, the Executive Committee herewith respectfully submits its report for the fiscal year ending October 31, 1947.

During this year the Executive Committee held five meetings, printed reports of which have been mailed to each Trustee and constitute a part of this report.

A statement of activities of the Institution is contained in the report of the President, which has been considered and approved by the Executive Committee, and is submitted herewith.

The detailed estimate of expenditures for the succeeding year contained in the report of the President has been considered by the Executive Committee, which has approved the recommendations of the President in respect thereto and has provisionally approved the budget estimates based thereon and submitted herewith.

The Board of Trustees at its meeting of December 13, 1946 appointed Price, Waterhouse and Company to audit the accounts of the Institution for the fiscal year ending October 31, 1947. The report of the Auditor, including a balance sheet showing assets and liabilities of the Institution on October 31, 1947, is submitted as a part of the report of the Executive Committee.

In addition to the report of the Auditor there is also submitted a financial statement for the fiscal year ending October 31, 1947, showing funds available for expenditure and amounts allotted by the Executive Committee, a customary statement of receipts and disbursements since the organization of the Institution on January 28, 1902, and a schedule of real estate and equipment at original cost. These statements together with the tables in the Auditor's report comprise a full statement of the finances of the Institution.

No vacancy exists in the membership of the Board of Trustees.

Frederic A. Delano resigned as Secretary of the Board of Trustees, and the Executive Committee, at its meeting of March 19, 1947, appointed Lewis H. Weed to fill the vacancy in the office of Secretary until the annual meeting. A vacancy, therefore, exists in the membership of the Executive Committee by reason of the resignation of Mr. Delano as Secretary of the Board of Trustees. Tenure of office of Messrs. Forbes and Walcott as members of the Executive Committee and of Messrs. Bradford and Prentiss as members of the Finance Committee will expire at the annual meeting.

WALTER S. GIFFORD, *Chairman*

ROBERT WOODS BLISS

VANNEVAR BUSH

W. CAMERON FORBES

HENRY R. SHEPLEY

FREDERIC C. WALCOTT

LEWIS H. WEED

November 1, 1947

FINANCIAL STATEMENT FOR FISCAL YEAR ENDING OCTOBER 31, 1947

Departmental Research Operations

	Balances unallotted Oct 31 1946	Trustees appropriations Dec 13 1946	Transfers and other credits	Total available	Executive Committee allocments	Transfers by Executive Committee	Unallotted Oct 31 1947
Embryology		\$90 754	\$24 127 69	\$114 881 69	\$114 881 69		
Genetics		126 760	42 260 84	169 020 84	169 020 84		
Geophysical Laboratory		192, 100	32 599 37	224 699 37	224 699 37		
Historical Research		128 153	20 163 91	148 316 91	148 316 91		
Mount Wilson Observatory		234 609	43 842 24	278 451 24	278 451 24		
Plant Biology		72 950	35 525 45	108,475 45	108 475 45		
Terrestrial Magnetism		259 000	149 841 85	408,841 85	408,841 85		
Research Projects of Limited Tenure	\$990 55		35,200 00	36 190 55	35 200 00		\$990 55
Publication	21 578 49	33 600	30 467 38	85 645 87	72,939 94		12 705 93
Administration		114 900	21 329 56	136 229 56	136 229 56		
Pension Fund		95 000		95 000 00	95 000 00		
General Contingent Fund	61 539 72		154 142 96	215 682 68	71 820 92	\$44 952 80	98,908 96
Carnegie Corporation Emergency Fund	215 338 16		3 162 25	218 500 41	101 400 00	1,200 00	115,900 41
	<u>\$299,446 92</u>	<u>\$1,347,826</u>	<u>\$592 663 50</u>	<u>\$2 239 936 42</u>	<u>\$1 965,277 77</u>	<u>\$46 152 80</u>	<u>\$228,505 85</u>

AGGREGATE CASH RECEIPTS AND DISBURSEMENTS FROM ORGANIZATION, JANUARY 28, 1902, TO OCTOBER 31, 1947

RECEIPTS		DISBURSEMENTS	
<i>Securities Sold or Redeemed</i>	\$116, 161, 248 21	<i>Securities Purchased</i>	\$131, 906, 931 58
<i>Income from Securities and Bank Balances</i>	56, 466 348 12	<i>Accrued Interest on Securities Purchased</i>	764, 987 18
<i>Sales of Publications</i>	..	<i>Pension Fund</i>	1, 856 307 10
<i>Colburn Estate (Bequest)</i>		<i>General Reserve Fund</i>	30, 477 43
<i>Harbary Fund (Gift)</i>		<i>Insurance Fund</i>	140, 532 24
<i>Harriman Fund (Sale of Land)</i>		<i>Harriman Fund</i>	298 49
<i>Teefle Estate (Bequest)</i>		<i>Harnel H. Mayor Relief Fund</i>	250 00
<i>Van Gelder Fund (Bequest)</i>		<i>Harkavy Fund</i>	221 20
<i>Carnegie Corporation of New York (Endowment Increase and for Specific Purposes)</i>	13, 705, 381 24	<i>Special Emergency Reserve Fund</i>	63, 819 41
<i>From Other Organizations and Individuals for Specific Purposes</i>		<i>National Defense Revolving Fund</i>	3, 062, 974 97
<i>Pension Fund (Refunds)</i>	487, 246 68	<i>General Contingent Fund</i>	342, 289 26
<i>General Reserve Fund</i>	99, 197 05	<i>Carnegie Corporation of New York Emergency Fund</i>	101, 444 77
<i>Insurance Fund (Refunds)</i>	72, 323 38	<i>Administration Building and Addition</i>	
<i>National Defense Revolving Fund (Refunds and Advances)</i>	13, 076 02	<i>Construction and Site (Old Building)</i>	309, 915 69
<i>Administration Building Addition Account Rentals and Refunds</i>	3, 094, 724 35	<i>Construction (Addition to Administration Bldg.)</i>	416, 206 07
<i>Employees' Salary Deductions for the Purchase of U. S. Bonds</i>	18, 021 09	<i>Site (Addition to Administration Building)</i>	68, 570 96
<i>Miscellaneous Refunds and Receipts</i>	91, 363 65	<i>Miscellaneous Expenditures*</i>	40, 825 37
	1, 184, 406 03	<i>Departmental Research Operations</i>	
		<i>Departments of Research, Buildings and Equipment</i>	3, 740, 042 88
		<i>Departmental Operations</i>	36, 222, 416 59
		<i>Research Projects of Limited Tenure</i>	5, 578, 395 61
		<i>Publication</i>	3, 063, 801 00
		<i>Administration</i>	3, 249, 282 86
		<i>Employees U. S. Bond Purchases</i>	91, 255 65
		<i>National Research Council</i>	150, 000 00
		<i>Miscellaneous</i>	9, 008 82
		<i>October 31, 1947, Cash in Banks</i>	\$191, 210, 255 13
			640, 539 91
			\$191, 850, 795 04

*Includes Equipment \$7 206 41 Repairs and Alterations to Old Building \$18 599 29

REAL ESTATE AND EQUIPMENT, ORIGINAL COST

Administration (October 31, 1947)

1530 P Street, N W , Washington 5, D C

Building, site, and equipment		\$850,933 59
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Division of Plant Biology (September 30, 1947)

Stanford, California

Buildings and grounds	\$74,125 72	
Laboratory	40,714 05	
Library	22,837 13	
Operating equipment	16,049 27	153,726 17

Department of Embryology (September 30 1947)

Wolfe and Madison Streets, Baltimore 5, Maryland

Library	\$7 619 92	
Laboratory	28,115 87	
Administration	8,774 90	44,510 69

Department of Genetics (September 30 1947)

Cold Spring Harbor, Long Island New York

Buildings grounds and field	\$299 239 47	
Operating equipment	34 397 95	
Laboratory apparatus	50,452 95	
Library	62,541 66	
Archives	45,488 90	492,120 93

Geophysical Laboratory (September 30 1947)

2801 Upton Street NW Washington 8 D C

Buildings library and operating appliances	\$295,654 22	
Laboratory apparatus	182,475 57	
Shop equipment	21,242 25	499,372 04

Division of Historical Research (September 30 1947)

10 Frisbie Place Cambridge 38 Massachusetts

Operating equipment	\$30,978 58	
Library	16 700 24	47,678 82

Mount Wilson Observatory (September 30 1947)

813 Santa Barbara Street, Pasadena 4 California

Buildings and grounds	\$222,549 56	
Shop equipment	52 798 69	
Instruments	675,531 90	
Furniture and operating appliances	162,042 62	
Hooker 100-inch reflector	644,803 88	1,757,726 65

Department of Terrestrial Magnetism (September 30, 1947)

5241 Broad Branch Road, N W , Washington 15, D C

Buildings, site, and office	\$265,794 67	
Survey equipment	21,891 99	
Instruments, laboratory, and shop equipment	457,220 92	744,907 58

\$4,590,976 47

REPORT OF AUDITORS

*To the Board of Trustees
Carnegie Institution of Washington
Washington, D. C.*

We have made an examination of the attached balance sheet of Carnegie Institution of Washington (and supporting schedule of securities owned) as of October 31, 1947 and the related statement of operating income and expenditures for the fiscal year then ended. In connection therewith, we obtained confirmations from the custodian, Guaranty Trust Company of New York, as to the securities owned by the Institution and held in safekeeping at October 31, 1947 and from the depositaries as to the cash balances in banks at that date. The interest maturing during the fiscal year on bonds owned was accounted for, and the dividends received during the year on stocks owned were compared with published dividend records. With respect to a period of three months selected by us the recorded cash receipts were traced to deposits shown on the bank statements and paid checks and approved vouchers were inspected in support of the head office disbursements. We did not visit the branch offices of the Institution but we reviewed internal audit reports of the Bursar covering examinations of the branch records during the year and it appeared that the internal audits were satisfactorily conducted. We also inspected certified copies of the minutes of meetings of the Board of Trustees and the Executive Committee with respect to the appropriations and allotments for the year.

The securities are stated at cost, amortized cost, or value at date acquired. In accordance with a recommendation made in February 1940 by the Institution's Finance Committee, premiums on bonds purchased subsequent to January 1, 1940 are being amortized on a straight-line basis to the dates on which the bonds are first callable or payable at par. The amortization of such premiums applicable to the year ended October 31, 1947 amounted to \$9,034.62. Real estate and equipment are stated at cost, and books on hand for sale are carried at sales prices. In accordance with accepted practice no provision has been made for depreciation of property owned by the Institution.

In our opinion, with the foregoing explanations, the accompanying balance sheet and related statement of operating income and expenditures present fairly the position of Carnegie Institution of Washington at October 31, 1947 and the financial aspects of its operations for the year ended on that date.

PRICE, WATERHOUSE & Co.

*Washington, D. C.
December 3, 1947*

BALANCE SHEET OCTOBER 31, 1947

ASSETS		LIABILITIES	
<i>Current Funds:</i>		<i>Current Funds:</i>	
General:		General:	
Cash in banks and on hand...	\$403,491.15	Accounts payable	\$ 227.25
Accounts receivable—Federal research operations—U. S. Government.....	31,116.96	Reserve for encumbrances: Departmental research projects of limited tenure	\$187,506.76
Accounts receivable—other.....	925.51	Publication.....	36,659.00
Inventory—books.....	1,703.59	Administration.....	81,946.68
Deferred charges.....	152,640.00		11,432.25
Due from Endowment and Other Special Funds (current cash invested in securities).....	18,105.78		317,544.69
		Reserve for publications and invoices	
		Reserve for General Continuation Fund.....	154,153.13
		Reserve for Carnegie Corporation Emergency Fund.....	135,939.23
		Reserve for special reconversion expenses	194,569.26
		Unexpended and unallocated current income, per statement attached.....	15,701.40
			139,848.03
			\$957,982.99
Restricted:		Restricted:	
Cash in banks.....	71,175.79	Harriman Fund—income account.....	71,175.79
			\$1,029,158.78
<i>Endowment and Other Special Funds:</i>		<i>Endowment and Other Special Funds:</i>	
Cash in banks.....	\$201,348.17	Due to Current Funds.....	\$350,000.00
Securities schedule attached:		Capital Funds:	
U. S. Government bonds.....	\$15,935,088.46	Endowment Fund.....	\$32,000,000.00
Foreign and International Bank bonds.....	854,368.71	General Reserve Fund.....	5,182,079.87
Public utility bonds.....	1,757,496.32	Collateral Fund.....	103,310.80
Communication bonds.....	204,335.50	Harriman Fund.....	304,043.70
Railroad bonds.....	274,484.45	Teagle Fund.....	10,839.76
Industrial and miscellaneous bonds.....	2,852,630.45	Harkavy Fund.....	2,828.80
Preferred stocks.....	4,671,385.32	Van Gelder Fund.....	1,278.58
Common stocks.....	13,717,495.41	Special Funds:	
		Pension Fund.....	189,965.02
		Harriet H. Mayor Relief Fund.....	9,750.00
		General Reserve Fund.....	2,109,546.76
			40,323,643.09
			40,673,643.09
<i>Plant Funds:</i>		<i>Plant Funds:</i>	
Invested in real estate and equipment:		Income invested in plant.....	\$4,409,278.42
Office of Administration.....	\$ 850,933.59	Harriman property (gift).....	179,628.05
Departments of research.....	3,740,042.88	Harkavy property (gift).....	2,070.00
			4,590,976.47
			\$46,293,778.34

GENERAL FUND

Statement of Operating Income and Expenditures for the Fiscal Year Ended October 31, 1947

Income

Interest and dividends on securities	\$1,502,714 14
Less—Amortization of bond premiums	9,034 62
	<hr/> \$1,493,679 52
Sales of publications	8,811 43
American Cancer Society—grants	14,360 13
Carnegie Corporation of New York—grant	12,000 00
State of Connecticut—contribution for survey	4,000 00
Dormitory and mess	7,842 11
Childs Frick Corporation—grant	300 00
Life Insurance Medical Research Fund—grant	1,000 00
Research Corporation—grant	5,000 00
United Fruit Company—Bonampak project	10,000 00
U S Public Health Service—grant	2,023 00
A F Zahm—gift	5,000 00
Other credits	5,428 89
	<hr/> \$1,569,445 08

Expenditures

Pension Fund—annuity and insurance	\$106 247 18
Carnegie Corporation Emergency Fund—grants	13,516 13
Harriman Fund—commissions	49 43
General Contingent Fund—miscellaneous expenses	17,463 92
Departmental research operations	
Salaries	\$856,304 11
Operating expenses	360,428 22
Dormitory and mess—salaries	3,048 01
Dormitory and mess—operating expenses	6 707 36 1,226,487 70
Research projects of limited tenure	
Salaries	\$13,161 52
Operating expenses	16,954 13 30 115 65
General publication	
Salaries	\$ 4,767 84
Operating expenses	35,011 79 39 779 63
Office of Publications	
Salaries	\$28,513 59
Operating expenses	5,698 59 34,212 18
Administration	140,052 27
	<hr/> \$1,607,924 09
Less—Salaries and operating expenses charged to previous appropriations	399,516 52 1,208,407 57
Excess of income over expenditures	\$361,037 51
Less Credits to General Reserve Fund and other accounts	221,189 48
Unexpended and unallocated current income	\$139,848 03

SCHEDULE OF SECURITIES OWNED OCTOBER 31, 1947

Aggregate per or nominal value	Description	Maturity	Cost, amortized cost, or value at date acquired	Market value	Interest income for year
UNITED STATES GOVERNMENT BONDS					
\$304,000	U. S. of America Treasury 2s	1951-49	\$304,000.00	\$308,085	\$6,080.00
312,000	U. S. of America Treasury 2s	1951-49	312,000.00	316,435	6,240.00
200,000	U. S. of America Treasury 2s	1952-50	200,000.00	202,938	4,000.00
4,500,000	U. S. of America Treasury 2s	1954-52	4,500,000.00	4,599,844	90,000.00
800,000	U. S. of America Treasury 2 1/2s	1955-52	800,000.00	824,750	18,000.00
1,250,000	U. S. of America Treasury 2 1/2s	1959-56	1,250,000.00	1,284,813	24,813.00*
2,170,000	U. S. of America Treasury 2 1/2s	1962-59	2,170,000.00	2,264,453	55,453.00
1,250,000	U. S. of America Treasury 2 1/2s	1964-59	1,250,000.00	1,284,813	24,813.00*
1,239,000	U. S. of America Treasury 2 1/2s	1964-59	1,239,000.00	1,284,813	24,813.00*
350,000	U. S. of America Treasury 2 1/2s	1967-62	350,000.00	362,578	6,578.00
1,200,000	U. S. of America Treasury 2 1/2s	1969-64	1,200,000.00	1,231,125	23,125.00
2,100,000	U. S. of America Treasury 2 1/2s	1969-64	2,100,000.00	2,132,813	32,813.00
50,000	U. S. of America Savings Defense "G" 2 1/2s	1953	50,000.00	47,900	1,250.00
50,000	U. S. of America Savings Defense "G" 2 1/2s	1954	50,000.00	47,900	1,250.00
100,000	U. S. of America Savings Defense "G" 2 1/2s	1954	100,000.00	94,700	2,500.00
100,000	U. S. of America Savings Defense "G" 2 1/2s	1956	100,000.00	95,600	2,500.00
100,000	U. S. of America Savings Defense "G" 2 1/2s	1957	100,000.00	96,900	2,500.00
100,000	U. S. of America Savings Defense "G" 2 1/2s	1958	100,000.00	98,800	2,500.00
100,000	U. S. of America Savings Defense "G" 2 1/2s	1959	100,000.00	98,800	2,500.00
Income from bonds sold					21,947.41
\$15,875,000	Total U. S. Government		\$15,935,088.46	\$16,179,371	\$356,851.11
FOREIGN AND INTERNATIONAL BANK BONDS					
\$100,000	Australia, Commonwealth of, S. F. 3 1/2s	1956	\$100,000.00	\$95,000	\$3,250.00
90,000	Canada, Commonwealth of, S. F. 3 1/2s	1957	48,750.00	47,500	—117.35
100,000	Canadian National Ry. Co., 4 1/2s Guar.	1951	90,146.36*	96,300	4,050.00
37,000	Canadian National Ry. Co., 4 1/2s Guar.	1957	112,000.00	114,000	4,500.00
100,000	Canadian National Ry. Co., 5s Guar.	1969	61,316.64*	62,130	2,850.00
100,000	Canadian National Ry. Co., 5s Guar.	1970	37,531.12*	38,500	1,750.00
200,000	International Bank for Reconstruction and Development, 2 1/2s	1957	100,000.00	99,000	—81.27
100,000	W. & P. Co., 4 1/2s	1957	208,460.00	208,460	6,000.00
100,000	City of Toronto Cons. Loan Deb. 5s	1949	90,104.59	105,000	5,000.00
Income from bonds called or sold					16,723.64
\$837,000	Total Foreign and International Bank		\$854,368.71	\$865,890	\$43,925.02

*After deduction for amortization of premiums on bonds purchased subsequent to January 1, 1940.

SCHEDULE OF SECURITIES OWNED OCTOBER 31, 1947—Continued

Aggregate cost, or market value	Description	Maturity	Cost, amortized cost, or value at date acquired	Market value	Interest income for year
PUBLIC UTILITY BONDS					
\$243,000	Columbus & Southern Ohio Electric Co. 1st Mtg 3½s	1970	\$257,782 92*	\$260,010	\$7,897 50
37,000	Greyhound Corporation, S. F. Deb 3s	1959	37,363 39*	37,000	1,110 00
200,000	Minnesota Power & Light Co., 1st Mtg 3½s	1975	204,593 90*	204,000	6,250 00
100,000	Ohio Power Co. 1st Mtg 3½s	1968	101,500 00	106,000	3,250 00
200,000	Ohio Public Service Co. 1st Mtg 2½s	1961	98,202 87*	98,940	2,788 75
200,000	Philadelphia Electric Power Co., 1st Mtg 2½s	1975	204,939 02*	196,000	1,792 75
200,000	Public Service Co. of Indiana, Inc., 1st Mtg 3½s	1975	204,604 80*	204,000	6,250 00
125,000	Puget Sound Power & Light Co., 1st Mtg 4½s	1972	129,512 42*	132,500	5,312 50
216,000	Tennessee Gas & Transmission Co., 1st Mtg Pipe Line 2½s	1966	218,997 00*	211,680	5,940 00
300,000	United Gas Corp. 1st Mtg & Coll Tr 2½s	1967	300,000 00	300,000	893 75
	Income from bonds called				15,613 03
<u>\$1,718,000</u>	Total Public Utility		<u>\$1,757,496 32</u>	<u>\$1,750,130</u>	<u>\$57,098 28</u>
COMMUNICATION BONDS					
\$150,000	American Telephone & Telegraph Co. Deb 2½s	1975	\$152,587 50*	\$145,500	\$1,260 42
52,000	New England Telephone & Telegraph Co. 1st Mtg 5s	1952	51,748 00	54,600	2,600 00
<u>\$202,000</u>	Total Communication		<u>\$204,335 50</u>	<u>\$200,100</u>	<u>\$3,860 42</u>
RAILROAD BONDS					
\$100,000	Chesapeake & Ohio Ry. Co., Gen Mtg 4½s	1992	\$99,464 29	\$131,000	\$4,500 00
75,000	Chicago & W. Indiana R. R. Co. Cons 4s	1952	70,357 66	77,250	3,000 00
100,000	Pennsylvania R. R. Co. Cons Mtg 4½s	1960	104,662 50	111,000	4,500 00
	Income from bonds sold				25,629 75
<u>\$275,000</u>	Total Railroad		<u>\$274,484 45</u>	<u>\$319,250</u>	<u>\$37,629 75</u>

*After deduction for amortization of premiums on bonds purchased subsequent to January 1, 1940.

SCHEDULE OF SECURITIES OWNED OCTOBER 31 1947—Continued

Aggregate par or nominal value	Description	Maturity	Cost amortized cost or value at date acquired	Market value	Interest income for year
INDUSTRIAL AND MISCELLANEOUS BONDS					
\$50 000	Devco & Railroad Co. Inc. S. F. Deb. 2 ¹ / ₂ %	1965	\$51 250 00	\$49 500	\$3 75
195 000	Eastern Gas & Fuel Auth. Deb. 2 ¹ / ₂ %	1965	198 819 59*	191 100	6 825 00
100 000	Food Machinery Corp. S. F. Deb. 2 ¹ / ₂ %	1962	100 500 00	99 000	—49 31
300 000	Goodrich B. F. Comp. 1 ¹ / ₂ % Deb. 2 ¹ / ₂ %	1965	301 342 12*	294 000	8 250 00
148 000	P. Lorillard Co. Deb. 3 ¹ / ₂ %	1963	155 327 79*	152 440	880 82
130 000	National Dairy Products Corp. Deb. 2 ¹ / ₂ %	1970	135 812 50	151 500	—114 58
145 000	Phillips Petroleum Co. S. F. Deb. 2 ¹ / ₂ %	1964	146 188 12*	146 450	3 987 50
250 000	Pittsburgh Courier-Publishing Co. Deb. 3 ¹ / ₂ %	1965	250 000 00	247 000	7 584 00
300 000	Rockwell Corp. Deb. 2 ¹ / ₂ %	1966	298 500 00	288 000	7 500 00
400 000	Shell Union Oil Corp. Deb. 2 ¹ / ₂ %	1971	405 629 09*	384 000	10 000 00
250 000	Socony Vacuum Oil Co. Deb. 2 ¹ / ₂ %	1976	249 185 00	240 000	6 250 00
200 000	Swift & Co. Deb. 2 ¹ / ₂ %	1972	203 697 55*	200 000	1 794 76
250 000	Union Oil Company of California Deb. 2 ¹ / ₂ %	1970	259 811 88*	247 500	6 875 00
100 000	United States Rubber Co. Deb. 2 ¹ / ₂ %	1976	100 347 85*	94 000	458 87
200 000	Westinghouse Electric Corporation Deb. 2 ¹ / ₂ %	1971	203 048 31*	198 000	3 959 38
Income from bonds called					
				842 73	
Total Industrial and Miscellaneous					
\$2 811 000			\$2 852 630 45	\$2 759 180	\$57 728 55
Bovons—Funds Invested					
\$21 713 000			\$21 878 403 89	\$22 073 921	\$537 093 13

*After deduction for amortization of premiums on bonds purchased subsequent to January 1 1940

SCHEDULE OF SECURITIES OWNED OCTOBER 31, 1947—Continued

Number of shares	Description	Cost, amortized cost, or value at date acquired	Market value	Dividends for year
PREFERRED STOCKS				
1,000	Anchor Hocking Glass Corp. \$4.00 Cum. Pref	\$112,750 00	\$107,000	\$4,000 00
1,500	Appalachian Electric Power Co., 4½% Cum. Pref	159,000 00	165,000	6,750 00
2,000	Armstrong Cork Co. \$3.75 Cum. Pref	205,500 00	200,000	7,500 00
1,500	Bethlehem Steel Corp. 7% Cum. Pref	183,637 50	213,000	10,500 00
1,477	Bristol Myers Co. 3¾% Cum. Pref	156,300 45	152,131	5,538 76
2,000	Buffalo, Niagara Electric Corp. 3.60% Cum. Pref	207,990 00	186,000	7,200 00
500	Case (J. I.) Co., 7% Cum. Pref	62,225 00	72,000	3,465 75
600	Cleveland Electric Illuminating Co., \$4.50 Cum. Pref	68,112 25	65,400	2,700 00
1,000	Columbus & Southern Ohio Electric Co., 4½% Cum. Pref	115,350 00	106,000	4,250 00
2,000	Consolidated Edison Co. of N. Y. \$5.00 Cum. Pref	213,490 00	210,000	7,500 00
1,125	Continental Can Co., Inc., \$3.75 Cum. Pref	115,312 50	114,750	4,218 76
1,145	Corn Products Refining Co., 7% Cum. Pref	115,312 50	114,750	4,218 76
900	Deere & Company, 7% Cum. Pref	25,931 25	29,700	1,260 00
1,125	duPont (E. I.) de Nemours & Co. \$4.50 Cum. Pref	116,125 00	138,375	5,062 52
1,500	Electric Power & Light Corp., \$7.00 Cum. 1st Pref	253,700 00	241,500	10,500 00
1,000	El Paso Natural Gas Co., 4.10% Cum. Pref	111,442 21	100,000	4,100 00
2,000	General Foods Corp., \$3.50 Cum. Pref	201,000 00	198,000	7,544 60
1,500	General Motors Corp., \$5.00 Cum. Pref	187,937 50	187,500	7,500 00
1,000	General Shoe Corporation, \$3.50 Cum. Pref	102,250 00	91,000	3,500 00
1,300	Goodrich (B. F.) Co., \$3.00 Cum. Pref	129,867 50	131,300	5,000 00
1,000	Goodyear Tire & Rubber Co., \$5.00 Cum. Pref	73,195 00	74,200	3,500 00
1,000	Grant (W. T.) Co., 3¾% Cum. Pref	100,447 91	98,000	3,750 00
1,500	McKesson & Robbins, Inc., \$4.00 Cum. Pref	144,000 00	144,000	6,000 00
1,000	Northern States Power Co., \$3.60 Cum. Pref	103,200 00	91,000	3,600 00
695	Ohio Power Co., 4½% Cum. Pref	76,552 00	77,145	3,127 52
1,500	Pacific Telephone and Telegraph Co., 6% Cum. Pref	235,220 75	223,500	9,000 00
1,000	Panhandle Eastern Pipe Line Co., 4% Cum. Pref	104,166 68	104,000	4,000 00
1,000	Pillsbury Mills, Inc., \$4.00 Cum. Pref	107,722 00	103,000	4,000 00
1,000	Public Service Co. of Oklahoma, 4% Cum. Pref	105,286 00	97,000	4,000 00
2,000	Public Service Co. of Ohio, 3.60% Cum. Pref	109,683 75	106,000	7,200 00
2,000	Reynolds (R. J.) Tobacco Co., 3.60% Cum. Pref	122,781 61	122,540	4,456 00
1,114	Servel, Inc., \$4.50 Cum. Pref	150,743 69	137,200	5,250 00
1,400	Sherwin-Williams Co., 4% Cum. Pref	150,743 69	137,200	5,250 00
1,400	Standard Oil Co. of Ohio 3½% Cum. Pref "A"	45,187 50	45,000	1,750 00
250	United States Gypsum Co., 7% Cum. Pref	443,407 57	440,200	21,700 00
3,100	U. S. Steel Corp., 7% Cum. Pref			
	Income from stocks called or sold	22,132 95		
43,405	Total Preferred Stocks	\$4,876,395 62	\$4,787,718	\$206,454 86

SCHEDULE OF SECURITIES OWNED OCTOBER 31 1947—Continued

Number of shares	Description	Cost amortized cost or value at date acquired	Market value	Dividends for year
COMMON STOCKS				
500	Abbott Laboratories	\$37 743 78	\$36 500	
200	Air Reduction Company	11 989 46	5 800	\$200 00
2 200	American Can Company	195 589 64	193 600	6 000 00
4 400	American Cyanamid Co	171 180 54	198 000	6 000 00
2 500	American Gas and Electric Company	107 153 93	92 500	5 225 00
2 700	American Telephone & Telegraph Co	399 025 39	421 200	24 300 00
3 700	Armstrong Cork Company	179 509 03	188 700	7 200 00
3 600	Boston Edison Company	174 036 54	164 805	8 640 00
500	Burlington Industries	149 571 25	150 000	6 000 00
2 800	C. I. T. Financial Corporation	147 957 73	128 800	5 600 00
700	Caterpillar Tractor Co	47 333 73	40 600	2 100 00
2 600	Chase National Bank of N Y	92 769 35	93 600	3 960 00
8 200	Chrysler Corporation	371 763 95	516 600	6 150 00
3 000	Cleveland Electric Illuminat Company	131 512 11	120 000	5 000 00
900	Coca Cola Company	121 233 75	165 600	3 675 00
1 100	Colgate Palmolive-Peet Company	43 776 74	49 500	5 775 00
2 000	Commercial National Bank and Trust Co of N Y	186 572 72	160 000	4 000 00
6 000	Consolidated Edison Company of N Y	187 523 40	160 568	7 575 00
2 000	Consolidated Gas Electric Light and Power Company of Baltimore	67 530 37	48 000	3 200 00
1 000	Continental Can Co	90 349 75	71 000	3 600 00
4 300	Continental Illinois National Bank & Trust Co of Chicago	172 761 85	150 500	4 300 00
1 200	Continental Insurance Co	105 810 90	100 800	4 800 00
3 308	Continental Oil Co of Delaware	131 593 72	162 092	5 616 00
6 000	Delaware Power & Light Company	162 943 08	294 000	13 500 00
5 100	DuPont Chemical Co	105 714 47	91 800	5 100 00
2 500	DuPont de Nemours & Co	399 376 04	462 500	20 625 00
11 500	Eastman Kodak Co	385 460 00	506 000	8 050 00
100	Fireman's Fund Insurance Co	8 700 00	8 900	
17	First National Bank of N Y	25 982 80	21 930	1 360 00
1 594	Food Machinery Corporation	90 962 22	127 520	3 187 00
11 200	General Electric Co	434 582 75	403 200	16 720 00
7 000	General Foods Corporation	293 688 31	266 000	13 650 00
8 000	General Motors Corporation	423 115 49	472 000	22 000 00
400	Goodrich Tire Co	21 580 08	21 000	2 000 00
200	Guaranty Trust & Rubber Co	31 355 98	27 600	3 000 00
10 000	Grant (W T) Co	181 260 49	290 000	22 500 00
400	Guaranty Trust Co of N Y	98 003 91	104 400	4 680 00
8 500	Gulf Oil Corp	366 532 37	603 500	21 250 00
1 700	Hartford Fire Insurance Co	148 651 06	175 100	4 250 00
8 000	Humble Oil & Refining Co	239 092 33	560 000	20 000 00
3 175	Insurance Company of North America	224 972 06	288 925	8 625 00
1 400	International Business Machines Corp	146 992 04	302 400	8 400 00
1 000	International Nickel Company of Canada Ltd	30 588 46	28 000	1 200 00
2 000	Ions-Menville Corp	108 000 00	111 000	4 800 00
1 500	Kennecott Copper Corporation	57 044 06	70 500	4 875 00
3 300	Kraze (S S) Company	75 867 59	125 400	9 570 00

(Continued on following page)

SCHEDULE OF SECURITIES OWNED OCTOBER 31, 1947—Continued

Number of shares	Description	COMMON STOCKS—Continued			Dividends for year
		Cost amortized cost or value at date acquired	Market value		
2 100	Lugnet & Myers Tobacco Co	\$189 977 30	\$186 900		\$8 925 00
300	Lund Carbonic Corporation	21 032 21	92 800		2 880 00
420	Mellon National Bank and Trust Company	67 193 07	96 800		2 880 00
1 600	Merck & Co. Inc	65 303 57	75 200		3 680 00
2 700	Minneapolis-Honeywell Regulator Co	123 415 63	159 300		6 480 00
6 600	Monsanto Chemical Co	211 865 19	402 600		13 200 00
6 300	Montgomery Ward & Co	339 979 26	359 100		18 900 00
5 300	National Cash Register Co	161 293 65	212 000		10 200 00
1 700	National City Bank of New York	68 889 50	98 700		2 720 00
1 700	National Fire Insurance Co of Hartford	72 819 72	98 700		2 720 00
1 800	National Life Fire Insurance Co	62 056 90	57 200		2 320 00
10 800	Newberry (J J) Co	143 047 69	313 200		22 680 00
2 300	New Jersey Zinc Co	147 347 02	138 000		6 900 00
3 600	Owens-Illinois Glass Co	248 890 37	266 400		10 125 00
2 750	Pacific Gas & Electric Company	121 073 09	101 750		5 125 00
8 400	Peoples Gas Light and Coke Company	267 016 94	369 600		25 200 00
1 000	Pepsi Cola Company	106 350 00	90 000		5 375 00
1 700	Pharmacia & Co. Inc	40 321 05	47 198		1 530 00
3 500	Phelps Petroleum Co	30 486 15	30 500		1 925 00
6 200	Phillips Petroleum Co	100 048 39	360 500		4 925 00
7 400	Putzbaugh Plate Glass Co	310 446 88	359 600		13 950 00
2 100	Procter & Gamble Co	228 162 48	288 600		9 620 00
1 000	Reynolds (R J) Tobacco Co B	117 585 87	149 100		7 875 00
1 500	Scott Paper Co	40 726 30	39 000		2 850 00
16 400	Sears Roebuck & Co	61 907 05	69 000		28 700 00
1 100	Sharp & Dohme Inc	374 427 57	623 200		1 100 00
4 900	Sherwin Williams Co	15 513 34	25 300		13 800 00
2 400	Smith Barney & Co	280 331 13	338 100		3 400 00
2 600	Southern Bell Telephone Co	140 697 14	168 000		5 600 00
2 800	Standard Brands Incorporated	106 459 15	75 600		5 880 00
8 300	Standard Oil Co of Indiana	274 147 21	340 300		15 600 00
5 800	Standard Oil Co of New Jersey	330 717 12	446 600		20 764 00
2 600	Texas Company	121 589 08	148 200		4 800 00
2 700	Tumken Roller Bearing Co	130 378 34	135 000		6 075 00
3 800	Union Carbide & Carbon Corp	333 875 55	399 000		14 250 00
9 400	United Fruit Company Co	266 728 02	526 400		32 900 00
3 200	United States Lysine Corp	289 316 34	367 800		12 000 00
9 200	Wabash Industries Corp	201 468 54	267 800		12 000 00
3 000	Woolworth (F W) Co	155 423 59	177 800		8 640 00
Income from stocks sold or exchanged					26 205 75
322 815	Total Common Stocks	\$13 717 495 41	\$16 797 088		\$739 166 15
366 220	COMMON AND PREFERRED STOCKS—Funds Invested	\$18 593 891 03	\$21 584 806		\$945 621 01
	AGGREGATE INVESTMENTS (BONDS AND STOCKS)	\$40 472 794 92	\$43 658 727		\$1 502 714 14*

*Represents total interest and dividend income before deduction of amortization of bond premiums

Note: Net gain from sales and redemptions of securities for the year ended October 31, 1947 aggregated \$98 378 71 and that amount has been credited to the Capital Reserve Fund shown in the attached balance sheet

REPORT OF THE PRESIDENT
OF THE
CARNEGIE INSTITUTION OF WASHINGTON
FOR THE YEAR ENDING OCTOBER 31, 1947

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REPORT OF THE PRESIDENT
OF THE
CARNEGIE INSTITUTION OF WASHINGTON

This report to the Trustees of the Carnegie Institution of Washington, presented in accordance with the By-Laws, is made at a time when the Institution, after the lapse of two years since cessation of hostilities, has generally resumed the fundamental studies to which under its charter it is customarily devoted. The interval of two years has seen the termination of the various war researches to which the skills of the Institution's staff and the facilities of its laboratories were directed while the country was at war. It has seen also a close scrutiny of past programs in the departments of the Institution, a restudy of objectives and of means earlier employed in seeking them, and a consequent reformulation of the basic plans by which the scientific work of the Institution is carried on.

Re-examination of objectives and re-assessment of procedures are, or should be, a continuing element in the conduct of any research program; they have been such in the operations of the Institution throughout its history. But only rarely indeed do circumstances so shape themselves that the revaluation becomes itself a primary undertaking extending practically throughout the Institution and done with the perspective gained from several years' preoccupation with activities considerably removed from those ordinarily carried on. The end of the war, however, brought such a situation, and thus an unusual opportunity for rigorous evaluation of the several programs of research by which, taken as a whole, the Institution carries out the mandate of its

charter, "to encourage, in the broadest and most liberal manner, investigation, research, and discovery, and the application of knowledge to the improvement of mankind."

Fundamental review of the range of departmental activity, comparative estimates of the urgency and the likely productiveness of individual projects, and analysis of the cross-linkages of projects and their impact on one another were thus possible. In this review, some studies carried on for a considerable period were found either to have served their purpose or to have reached a point where they should be carried forward by other agencies. Others were judged to have developed to a point demanding that greater emphasis be placed upon them. There were clearly indicated opportunities for the initiation of new specific undertakings as additional or more powerful approaches to the major objectives of certain departments; the requirements involved were carefully scrutinized, the means available for meeting them were reviewed, and the necessity for additional techniques, instrumentation, and staff was clearly defined.

The programs thus prepared are an able plan of action. The Standing Committees of the Trustees have reviewed certain of them; final study of others is in process or prospect. From the programs as a group we may expect added effectiveness in the application of knowledge to the solution of basic problems. Such programs are not regarded as rigid prescriptions beyond the limits of which no effort is to be

expended, however important the occasion, but rather are seen as efforts to limn the unknowns and to educe ways of ultimately filling in the outlines and rendering the picture sharp.

Two general observations of no small significance emerge from consideration of the process of analysis and formulation which has produced these programs: First, we rightly take from it renewed confidence in the central philosophy of the Institution as an organization engaged in the conduct of fundamental scientific investigation; second, we have in it a further example of the effectiveness of the pattern of administrative organization which has been developed.

From its inception, the Institution's philosophy has stressed a truth often too easily ignored in the marshaling of strength for advancement of knowledge. This truth is that research stands or falls by the men who are called upon to do it. In its earliest days, the Institution followed the consistent policy of seeking the exceptional man, wherever he might be, and making available to him facilities and resources to enable him to pursue problems which he discerned and by methods which he devised. In later years, establishing its own research centers for organized effort in major intellectual fields, the Institution has held to the thesis that such centers, however elaborately and efficiently equipped, are insufficient in themselves and are of ultimate value in the search for knowledge only as they are utilized by groups of investigators including leaders of proved skill and acumen and younger men of brilliant promise. They must be men of ingenuity and initiative; and these qualities must be unified and vitalized for effectiveness by breadth of vision and keenness of perception, in short, by a truly philosophical understanding.

The Institution is fortunate in its scientific staff, and never has this been more clearly demonstrated than in the deliberations leading to the formulation of the programs I have mentioned. Here, in free exchange and uninhibited discussion, the knowledge and aspirations of individual investigators were balanced and combined, the impact of programs one upon another was estimated from the point of view of firsthand comprehension, and a task of analysis and comparison was performed by the joint action of colleagues. Thus the cardinal principle—that in fundamental research the finding of the approach is in essence the function of the scientist himself—has been followed, yet through collaboration and interchange the result has been more than a collection of individual projects. It has been a coherent and consistent general plan.

I have placed great emphasis in the foregoing on the creative work of the Institution's scientific staff in this task of analysis and redirection, because that work is the primary motivating force in the whole affair. I do not at all intend to imply, however, that the resulting general program of the Institution's research was created in isolation from the Institution as an entity. Quite the contrary is true, and it is true because of the effectiveness of the administrative structure of the Institution. I should like to speak next of this, and in some detail.

From one point of view, the Institution as a continuing body is the self-perpetuating Board of Trustees who, responsible for the administering of its funds in the public interest, are the arbiters of its long-range policy. From another point of view, the Institution is the staff of scientific investigators who in the laboratory, the library, and the field are engaged in the actual research whence comes the application of

knowledge to the improvement of mankind, and who are served by the administrative and supporting staffs of the Institution in their various capacities. Actually, the Institution is neither of these singly; rather, it is a dynamic whole incorporating both. Its organization is distinctive, partaking on the one hand of the pattern found in corporate enterprises, and on the other of the intimate relationships existing in university faculties. And not simply on rare occasions, but in the day-to-day functioning of the whole, these aspects of its organization are found to be interpenetrating.

The Trustees, charged with the responsibility of exercising the final, long-range judgment in Institution affairs, do more than this. They are in their capacity as trustees concerned naturally in the first instance with the relationship of the programs of the Departments to the resources of the Institution. Theirs is the important function, moreover, of the final review of programs, the study of over-all planning with the ultimate objectives of the Institution in mind. Here sound sense in weighing possibilities and attainments is imperative for the continued effectiveness of the Institution. The broad outlook of the Trustees and their wide range of interests would by themselves assure the desired keenness of judgment. The Trustees can, however, and do, participate individually and officially with the staff in the consideration of plans and of particular ways of implementing them, even before the stage of final survey and analysis has been reached. This desirable interchange has been of direct helpfulness and value in the deliberations of the past two years. Individual members of the Board of Trustees possessing special knowledge and experience in various disciplines have contributed therefrom in discussion, with beneficial re-

sult in the formulation of programs. The Standing Committees of the Board, acting as such, have similarly shared in the engrossing work of planning. Fortunately enough, there has been a minimum of formality in this joint effort, and the soundness of the programs, as well as the spirit of the Institution, has been enhanced by that fact.

The Directors of Departments and Chairmen of Divisions in the Institution occupy posts demanding a rare combination of abilities. The position of the director is marked even more strongly by that duality which I have noted in the functioning of the Trustees. The director can and should be both an investigator and an administrator. As an investigator he joins with his colleagues on a plane of equality in planning a scientific program in which all participate and in which he has his unique part. As the director he administers the program, resolves differences of view, and maintains contact with the President and Trustees. To meet this dual responsibility, he must be a scientific worker of proved ability, and he must possess the qualities of leadership, inspiration, and firmness that evoke the best efforts of colleagues and keep operations moving in the agreed direction. He must likewise have the ability at understanding and guidance for which younger members of the staff will look to him. Thus as an investigator he shares the duty of all scientific men toward rigor, vision, and collaboration. As an administrator, he faces the same duties and needs the same capabilities as does the head of a department in an academic institution and, to some extent, as does the director of research in an independent laboratory.

It is through his over-all grasp of the programs proposed within his group that interrelationships may most readily be as-

certained, comparative values may be judged, and suitable adjustments may be made to produce an integrated result. As investigator, he sees with a scientist's eye the implications of the problems posed and the procedures planned by his colleagues. As administrator he brings the necessary added strength and resiliency to handle problems of operation as they arise, to focus enthusiasm in such a way as to avert waste effort, to keep a weather eye out for economic hazards. It is a unique combination of skills, and it poses severe demands. The internal relationships through the staffs of the Departments and Divisions of the Institution are cordial and unassuming, and the fact that they are so is evidence indeed that this requirement for a rare combination of insight and initiative is well met. From supporting administrative staffs, Directors and Chairmen receive the best of support, and since the spirit of the Institution is on an excellent plane, the ideal of a community of scholars is approached.

I should say a word about the function of the President of an institution such as this. He is in a post where his responsibility essentially is to work with the staff on the one hand and the Trustees on the

other to bring together the aspirations of the staff, as expressed in considered programs of research, with the possibilities and resources of the Institution itself. In doing this, he of course works closely with the Directors and Chairmen and, sometimes through them, sometimes directly, with the members of the scientific staff. Here again, as has already been suggested, formality should be and is at a minimum.

The general plan of organization thus roughly summarized had been proved in effectiveness well before the especial demands of these recent years. In these years, however, and especially as the formulation of programs has gone forward since the end of the war, the structure of the Institution has been stringently tested, and has met the test. The result may be summed up in the thought that immediately before us are sure prospects for coherent, consistent, vigorous work in our special fields of endeavor, with high assurance that the contributions of the Institution to the general welfare will be substantial and that they thus will bring to all the organization, Trustees, administration, and staff, the lasting satisfactions to be had only from work well done.

THE INSTITUTION AND FEDERAL SUPPORT

In common with many other research agencies in the country which because of the nature of their regular undertakings could adapt facilities and allocate staff, the Institution during the war years sought to carry its full share of the burden of research on military matters essential for the maintenance of national security and the defense of the American way of life. Much if not most of the work which the Institution thus did was only remotely, if at all, related to the programs of investigation which it had carried on in peacetime. Virtually all of it was done under the restric-

tions of secrecy necessary in the military operations of a nation at war. Lastly, the great bulk of the undertaking consisted of applied research. For these reasons, the Institution at the end of the war terminated all research for the government as expeditiously as possible; in view of its original purpose, the Institution needed to return to its own programs of fundamental research and its own policy of free dissemination of results. With the end of hostilities, such action became practicable and proper, for the obligation to share the war burden was past, and the laboratories of

the armed services as well as of industry were available to carry on such secret applied military research as the well-being of the country demanded.

The war experience carried salutary effects for the Institution, altogether apart from its natural pride at having shared in the defense of the nation. The war experience was the principal occasion in the Institution's history when it was engaged in undertakings financed otherwise than through its own income from endowment, and the first occasion in its history when for an extended period and under intensive conditions it operated in close relationship with the government. The comprehension thus gained is of marked value in our consideration of the future.

There is a fundamentally important difference in that future—indeed, in the immediate present—for research in this country. This appears because of the entrance of the government into the financial support of basic research. Federal funds are now going on a broad scale to the support of fundamental investigation in many centers throughout the nation. Much of the flow is from the armed services, notably from the Navy. By no means all of the support is from the military, however. The Atomic Energy Commission, for example, is contributing very substantially through the laboratories which are operated for it under contract by groups of universities. The Public Health Service and the Department of Commerce within their fields are other agencies sharing in the support of research. There is a notable difference not only between this situation and the prewar condition, in which government's role was of slight dimensions, but also between this situation and that which existed during the war. Then, federal money supported great programs, but they were principally programs of applied re-

search for the early attainment of a specific objective, and they were principally secret. Now, federal money is supporting fundamental studies, and the restrictions upon dissemination of results are far less exacting. The policy governing federal grants and contracts for fundamental research under these more liberal conditions has thus far been broad and wise.

Since the end of the war it has been the policy of the Institution not to seek broad support of its research from federal funds. There has appeared no reason why this policy should now be altered. Yet there would be no inconsistency between the policy and occasional participation in federally supported programs, or even the acceptance of direct federal support to a minor degree and in special circumstances for research which is complementary to our regular programs. It is therefore proper to examine again whether the Institution should consider participation in the research efforts being sponsored by the government and supported by public funds, and if so, under what conditions. Should it enter the program, it would be joining many other ranking research organizations, for participation is widely spread through the country. Certain considerations in part deriving from the program itself and in part from the individual characteristics of the Institution must be taken into account in appraising the possibility. Participation could be expected to enlarge operations, but should not be regarded as lessening budgetary problems. The agreements under which governmentally supported programs are conducted are, as they should be, so drawn as to cover all costs, including added overhead, but no more. Were the Institution to undertake a research project supported from federal funds, its regular schedule of operations would not and should not be

affected thereby; its total range of activities, however, would be increased. Such expansion in and of itself has little to recommend it to an institution such as ours, for size is not a true objective for us. In so far as expansion might clearly have an invigorating effect on regular programs by increasing possibilities of cross-fertilization and stimulation, though, it may be considered advantageous.

For many universities, which are carrying on a broad range of research projects supported from federal funds under the present arrangement, there may on the contrary clearly be a special and positive advantage in such expansion. Fundamental research is of course pursued in university laboratories for its own sake, but in addition it is essential in the postgraduate training of scientists and engineers. As the universities, particularly at the graduate level, seek to overcome the deficit of fully trained men resulting from short-sighted handling of special manpower during the war, they hence are confronted by a need for the expansion of research. Participation in the federally supported program has enabled them to expand research opportunities as they otherwise would not have been able to do, inasmuch as university income from endowment has definite limits.

The Institution of course wishes to collaborate in broad programs in which many organizations thus participate. Without seeking government support, it may collaborate in undertakings to which its own regularly programmed investigations are related. If clear opportunity arises, in which firm values can be discerned from extension of collaborative effort by the Institution through the introduction of particular new projects in addition to regular programs, then the Institution may be well advised to enter forthrightly into

the governmentally sponsored endeavor. The policies that should govern acceptance of funds for the enlarging of research programs are clear, whether the funds in question are made available by the government or by other agencies.

In the first place, a research activity undertaken by the Institution as an addition to its regularly programmed investigations and as a result of the availability of financial support specially provided by government or another supporting agency and specially allocated to the project in question must form a clearly defined addition, as nearly as possible an integral operative and administrative unit by itself. If the support terminates, it is essential that the Institution be in a position to bring the activity to a termination and be free thereafter of any remnants of it. This condition cannot effectively be met unless the project is by nature clearly defined. The funds through which it is supported must be used only for temporary additions to the staff, and the overhead expenses added by the presence of the project must be distinguished from regular overhead so clearly that cessation of payment of overhead charges in connection with the project can almost automatically bring about cessation of the charges themselves.

In the second place, though this criterion hardly need be stated, since it is fundamental in the Institution's philosophy, the activity should be in and of itself worth carrying on. There is no benefit in pursuing a remote research simply because funds for it are available, and there is an obligation on investigating agencies to guard against the disbursement of funds, whether their own or those of others, for the pursuit of secondary objectives, however attractive they may be, as they occasionally are. Beyond this requirement that the project be one of substantial worth

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in itself, it should also be a natural addition to the Institution's own regular programs. If this requirement is not met, distraction or diversion of interest or effort which might result from the presence of pronouncedly unrelated projects, however worthy in themselves, could reduce in effectiveness the results sought in the disbursement of our own funds.

In the third place, and closely akin to the second standard, is the requirement that the activity undertaken in addition to regular programs be one to which the Institution can genuinely contribute by reason of the skills and operations of the regular staff and the presence of the regular programs. This is another way of saying that there should be a reason why progress in the new activity promises to be more rapid or more fruitful if the Institution rather than some other agency enters upon it. Throughout the range of scientific investigation, whatever the field, there are potential gains to be had from such intangibles as chance conversations between research workers on related problems, or the spirit of emulation which arises when new projects come into an established program, stimulating it to added effort and in turn being stimulated to match the roundedness and stability which it possesses.

In the fourth place, the conditions under which the Institution accepts added funds, federal or other, to extend its programs should be proper. They should in no way infringe upon the independent status of the Institution in the pursuit of its own regularly programmed research and they should be genuinely adapted to the sound prosecution of fundamental investigation of the highest quality. Acceptance of the funds should impose no obligation upon the Institution other than the obligation to expend them wisely, in accordance with

its own practices regarding its own funds, and subject to regular and proper accounting. I have said already that the policy governing grants by the national government for fundamental research has thus far been excellent in its vision and wisdom. It is highly important for the well-being of the country that the federal policy should thus continue, but there can be no warranty that it will. Hence two further requirements should be stated, even although at present there is no need for emphasis upon them. These are that contracts into which the Institution enters should not contain clauses likely to produce later embarrassment, and that they should contain termination clauses which would enable the Institution to withdraw whenever the major criteria here outlined ceased to be met.

The general standards of policy with which we have been dealing apply primarily to undertakings of major size. Certain other types of participation which the Institution might assume in research endeavors outside its own regular programs are very simple and require little analysis. For example, there is no reason why the Institution should not accept gifts or loans of apparatus for use in its own research programs, or in added activities, provided there is no undue risk in the responsibility for return of the equipment in acceptable condition. Similarly, should a federal program involving several organizations parallel one of its own programs, the Institution can become a collaborator with others, using its own funds. Should circumstances warrant, and should the major criteria be met, the Institution might subsequently increase its activities in the field in question, accepting support from outside and undertaking projects in addition to its regularly programmed studies.

CARNEGIE INSTITUTION OF WASHINGTON

In the fields of its special competence, the Institution in the past has had, and now has, much opportunity for collaboration of a different sort. This is in an advisory capacity. If a federal department is carrying on a program in fundamental research closely allied with our own programs, a department of the Institution or the Institution itself may appropriately engage in advisory service if requested. The rendering of advice on undertakings closely cognate with our own has a double benefit; not only may it contribute to the

undertaking, but also it may be counted on to aid our own thinking and progress. Such advisory service as this is apart from advisory services to governmental agencies and similar organizations by members of the staff as individuals. There is no doubt that scientists generally have an obligation to respond as individuals to calls from their government particularly for advisory services, and the Institution should assist members of its staff to meet such calls, assuming that they are reasonable in extent and character.

RESEARCH ACTIVITIES

This report year is the first one since 1940 during which all the Departments and Divisions of the Institution have been fully engaged in normal programs of investigation. The evaluation of possible undertakings and the consequent formulation of well rounded programs on which careful effort was expended during the year previous have already more than justified themselves through the coherent and vigorous over-all pattern of the Institution's research activities this year. The reports of the Departments and Divisions review these in detail; a few results of particular interest will be summarized here.

Implications of possible significance to several subjects of marked importance attach to the continuing investigation of the general magnetic fields of stars which Dr. Horace Babcock is carrying on at the Mount Wilson Observatory, having made his initial effort last year. Now, for the purpose of discovering stars possessing strong magnetic fields, he has surveyed likely ones down to the sixth magnitude, finding magnetic fields stronger than 1000 gauss in several, and a polar field of some 5500 gauss in one. Since these stars are probably in rapid rotation, the discovery

of magnetism in them may contribute to knowledge of the relationship between the magnetic and mechanical properties of large rotating masses, to understanding of rotating stellar systems such as our galaxy, and possibly to theories of the cosmogony of planetary systems.

The newly integrated program of research at the Geophysical Laboratory presented last year specific approaches to the general objectives that had been decided on, and during the present report year active advance on these has been made. The development of a new type of pressure apparatus has facilitated the study of equilibrium relations in hydrous mixtures, the magnesia-silica-water system having been under principal investigation. Here it was found that all the more common natural hydrous silicates of magnesia, as well as two anhydrous silicates, can be prepared with only the solid phases and vapor present. The silicates formed in the experiments performed thus far are common in certain varieties of igneous and metamorphic rocks; the conditions of their formation in nature may be more clearly understood as knowledge of their range of stability with respect to pressure and temperature is extended. This fresh start on

the wet silicate problem will contribute to increasing that knowledge. Equilibria up to 900° centigrade at pressures up to 15,000 pounds per square inch, and at 800° centigrade and pressures of 30,000 pounds per square inch, have been determined in the new apparatus.

The cosmic-ray program of the Department of Terrestrial Magnetism over the past twelve years has comprised long-continued observations of the intensity of cosmic radiation at various stations throughout the earth. During these, slight variations occasioned by atmospheric changes and decreases of a few per cent occasioned by the increased magnetic moment of the earth following magnetic storms have regularly been observed. A surprising phenomenon, however, was noted at the time of a marked solar flare and radio blackout on July 25, 1946; the occurrence was accompanied by a large *increase* in the intensity of cosmic radiation at all observing points except at the equator. About a day later, a magnetic storm took place, with its usual effects. Dr. Tuve in reporting this event points out that the known change in the earth's magnetic moment due to ionization by ultraviolet light cannot explain it, and that the flare effects cannot readily be assumed to have altered the sun's magnetic moment enough to pass an increased number of cosmic rays. An accelerating action associated with the flare at or near the sun may possibly have produced the additional rays. Two similar occurrences in 1942 were revealed by search of the records.

Indication that the magnetic field of the earth has not changed in strength, to within the accuracy of the measurement, during the past 30,000 years has been obtained through the use of new procedures developed in the Department's investigations during the past year. The faint resid-

ual magnetism in the layers of silt deposited by retreating glaciers at the end of the last ice age had been measured before the war, with the object of tracing deviation of the compass direction from true north. The new techniques, in which the silt from single layers is redeposited out of a water bath in a magnetic field, afford a tentative measure of the intensity of the earth's field in that distant period.

The amazing diversity of the form and structure of plant life is among the most striking developments of the evolutionary process. Yet in one, and a vital, respect plant life today has altered only in minute detail from its earliest progenitors; the fundamental process of photosynthesis by which plants manufacture their food appears to have undergone little change in the long course of evolution during which structure, habit of life, and function itself have been modified. Research in the Division of Plant Biology involving extensive study of a wide variety of plants has given basis for this conclusion. The chloroplast pigments that are essential in the photosynthetic apparatus of all plants are found to have changed but little in the evolution not only of the species in major taxonomic groups, but also of the main groups themselves. Thus it is indicated that the photosynthetically active pigments of present-day green algae, for example, are the same as those possessed by their fossil ancestors of several hundred million years ago. The Division's continuing study of the unicellular alga *Chlorella* has given a result which bears interestingly on this conclusion. The chemical composition of the alga varies with the culture conditions selected for its growth, running to 5 per cent of fat under one set of conditions, and to 85 per cent under another. The chlorophyll content of the cells in the first case is high; in the second case, it is low,

only about one one-thousandth of the content of the cells of low fat production. But in both cases, the nature of the chlorophyll pigments is the same.

The grass-breeding program undertaken by the Division of Plant Biology in cooperation with the Soil Conservation Service of the United States Department of Agriculture for the practical purpose of producing a better range grass to augment food supplies has resulted in nearly three hundred interspecific hybrids, some of which show high promise because of their combination of favorable yield, resistance to disease, and continued activity in dry summer weather. The species used in the crossings produce most of their seed asexually and hence breed true. The program took advantage of this fact to help in the quick establishment of desirable hybrids. Unexpectedly, it was found that two-thirds of the hybrids between asexual parents were themselves sexual. There is possibility that these sexually reproducing hybrids between asexual parents may themselves in later generations produce apomictic, or asexual, forms, which might permit breeders to seal up the variability of plants for an asexual period, then release it for a time, and finally seal it up again. Both theoretical and practical purposes could thus be served. It is unusual in scientific endeavors for a project in essentially applied research for an immediate and utilitarian purpose to eventuate in promising prospects for fundamental investigation, as the range-grass program is doing. Generally, the reverse of this process is true.

The aerosol method developed in the Department of Genetics during the past two years for investigations involving the treatment of *Drosophila* with chemical solutions has been employed to test the power of various cancer-producing agents to bring about mutations in genes. A

majority of the carcinogens thus tested have been found to be mutagenic; of substances chemically related to the carcinogens but themselves non-cancer-producing, a majority do not produce mutations. The chemical carcinogens studied behave in the same way as do all known nonchemical cancer-producers, such as X-rays and similar radiations, ultraviolet rays, and heat, for all these are also mutagenic. Dr. Demerec points out that the hypothesis that cancer may originate through a gene mutation occurring in a somatic cell suggests the most probable relation between mutagenicity and carcinogenicity.

The study of the genetic structure of natural populations carried on by Dr. Dobzhansky, Research Associate, as part of the program of the Department of Genetics has shown that the proportion of certain types of *Drosophila* in wild populations changes with the season. Varying the temperature in laboratory experiments produces similar changes in the make-up of populations. The fly thus shows substantially the same kind of differentiation into altitudinal races as was found true for certain plants by Drs. Clausen, Keck, and Hiesey of the Division of Plant Biology in their five-year study of *Achillea*, the results of which are in process of publication. The fly undergoes the process of adaptation regularly and cyclically, twice each year, since it is capable, at least at the lower elevations in the California mountains where the study was conducted, of producing several generations annually.

Among the group of associated studies in which Dr. Louis B. Flexner and his associates are utilizing tracer techniques in the Department of Embryology, one employing radioactive sodium and heavy water has given a definite answer to the important questions of the proportion of water in the body, by weight, in newborn

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infants, and the distribution of it as between cells and the blood, other body fluids, and extracellular spaces in the tissues. The newborn infant is found to be 74.6 per cent water, and the extracellular water accounts for 43.5 per cent of its body weight. These figures, obtained from living healthy infants, agree very closely with earlier findings obtained by other means, and reinforce evidence that the ratio of water within the cells to extracellular water increases as growth goes on. This group of studies employs tracer materials prepared in the cyclotron of the Department of Terrestrial Magnetism, and members of the scientific staffs of the two Departments are working closely together in the program. Further studies of the permeability of the placenta are being carried on.

Better understanding of the problems of advanced pregnancy and of parturition is sought through the comprehensive study of the physiology of the pregnant uterus and of the fetus which is being carried on by Dr. S. R. M. Reynolds, of the Department of Embryology, in which the physical forces involved as the uterus accommodates to its growing contents are being investigated. Incident to this work has been the development of an instrument to re-

cord the contractions of the late pregnant and parturient human uterus, which employs sensitive strain gages applicable to the abdomen and providing a tape record of the uterine contractions.

Work done during the past year has shown that the discovery at Nebaj in the highlands of Guatemala in 1946 was of even greater archaeological significance than had at first been suspected. The thorough investigation possible during the 1947 field season disclosed a number of burials in the mound opened in 1946, and yielded a plaque regarded as the finest single example of Maya jade carving yet brought to light. Some seven or eight centuries are spanned by the works of art recovered from the burials in this single mound. Another valuable aspect of the work of the Division of Historical Research during the year was in the direction of an expedition to Bonampak in Chiapas, where ruins containing well preserved wall paintings of the highest importance had been discovered by Giles G. Healey, explorer and photographer for the United Fruit Company, in co-operation with which the archaeological study was initiated. The frescoes, dating from the eighth century, are lavish in detail.

STAFF

Administrative responsibilities in the Division of Plant Biology were assumed on July 1 by Dr. C. Stacy French, who succeeds Dr. Herman A. Spoehr as Chairman of the Division. Having served as Chairman for fifteen years, Dr. Spoehr will devote full energies to his researches on the products of photosynthesis.

Dr. French, who came to the Institution from the University of Minnesota, where he was associate professor of plant physiology, has made notable contributions to the study of photosynthesis by his investiga-

tions of the Hill reaction—the evolution of oxygen from chloroplasts suspended in solution. The apparent similarity of this reaction to the oxygen evolution step in normal photosynthesis in the living plant makes it of great interest. Dr. French is known also for his investigations of cellular respiration and of the photosynthesis of purple bacteria. He has been a research fellow at the California Institute of Technology and an Austin teaching fellow at Harvard University, where he completed doctoral studies in 1934.

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Dr. Spoehr in 1910 joined the staff of the Institution's Desert Laboratory, one of the research units which subsequently were linked in the creation of the Division of Plant Biology. Serving as Chairman of this Division for three years beginning in 1927, Dr. Spoehr then spent a year as director for the natural sciences of the Rockefeller Foundation, returning to the chairmanship of the Division in 1932.

Walter M. Gilbert retired from the post of Executive Officer of the Institution on March 1, 1947, after service of more than forty-two years. Thus a central figure in the operational and administrative conduct of the affairs of the Institution through practically its entire history, he was on his retirement the senior member of the professional staff in length of service. He has been succeeded by Paul A. Scherer, a consulting engineer in heat transfer and refrigeration, whose ability as an administrator was demonstrated during his service as chief of the engineering and transition office of the Office of Scientific Research and Development.

Dr. Margaret Reed Lewis, who retired from the Institution's scientific staff in December 1946 after more than thirty years of research in the Department of Embryology, where she made many valuable

contributions in cytology, is continuing at the Wistar Institute her studies of immunity and resistance of cancer cells.

After a year's leave of absence during which he rendered notable service as the first Executive Secretary of the Joint Research and Development Board of the War and Navy Departments, Lloyd V. Berkner returned in the fall to his post as Chief of the Section on Exploratory Geophysics of the Atmosphere of the Department of Terrestrial Magnetism.

The achievement award of the American Association of University Women was presented to Dr. Barbara McClintock, of the Department of Genetics, at the Association's biennial convention in Dallas in April. It is pleasing recognition of the value of her research in the cytogenetics of maize, which is contributing to the advance of knowledge of evolution and heredity.

The Viking Fund Prize and medal in archaeology for 1946 were awarded to Dr. Alfred V. Kidder, Chairman of the Division of Historical Research. Presented annually by the Society for American Archaeology, the award is made to the person considered to have made the outstanding contribution to archaeology in the award year.

FINANCES

Though we are in the midst of a period of generally rising costs, careful study of the programs and commitments of the Institution, in which departmental, divisional, and administrative totals together with various special expenses have been analyzed, has served to keep the Institution operating within its income. The leeway between income and necessary expenditures has of course been seriously lessened both by low interest rates and by the widespread increase in the cost of

living, which affects institutions as it does individuals. The salary and wage scales of the Institution are steadily being brought nearer a level fully comparable with those of other principal research and educational institutions. Though they are lower than the maximum in the foremost group, they remain well up in that group. In the course of adjustment, we have now reached the end of the process of closing down matured or auxiliary efforts, so that the program of the Institution is now reduced

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to the central core of its regular departments.

The Institution's reserves continue adequate. During the war years, diversion from regular activities made it possible to augment reserves through revertments of about \$1,000,000. Reserves were drawn upon moderately for nonrecurring items in the launching of the new research programs formulated after the end of the war.

Establishment of a new method of

budgeting, whereby proposals of expenditures are made on the basis of a total figure determined by the Finance Committee as reasonable for budgeting purposes, is an important change in Institution financial procedures. It is expected to be helpful in stabilizing operations at an effective level within funds available, even although the nature of our portfolio presupposes fluctuations on a long-term basis which will need to be cushioned by the use of reserves.

REPORTS OF DEPARTMENTAL ACTIVITIES AND CO-OPERATIVE STUDIES

ASTRONOMY

Mount Wilson Observatory

TERRESTRIAL SCIENCES

Geophysical Laboratory

Department of Terrestrial Magnetism

Special Projects

BIOLOGICAL SCIENCES

Division of Plant Biology

Department of Embryology

Department of Genetics

Special Projects

HISTORICAL RESEARCH

Division of Historical Research

MOUNT WILSON OBSERVATORY

Pasadena, California

IRA S. BOWEN, *Director*

Last year's report recorded the announcement of an agreement between the California Institute of Technology and the Carnegie Institution of Washington for the joint operation of the Palomar Mountain Observatory, with its 200-inch telescope, and the Mount Wilson Observatory. This joint operation of the two observatories will become effective on the completion of the 200-inch telescope, which is expected to occur during the coming year, 1947-1948. In the meantime plans are being actively studied to bring about this unification of the scientific programs of the two observatories in the most effective manner and with a minimum of disturbance to the present personnel of the two institutions.

Pending the initiation of the joint operation and the installation of the permanent administration, a Preliminary Joint Management Committee has been appointed to make the necessary plans. This committee consists of the following members: Max Mason, Chairman of the Observatory Council, Richard C. Tolman, Professor of Physical Chemistry and Mathematical Physics, and E. C. Watson, Chairman of the Division of Physics, Astrophysics, Mathematics, and Electrical Engineering, from the California Institute; Walter S. Adams, Research Associate, Edwin P. Hubble, Astronomer, and I. S. Bowen, Director, from the Mount Wilson Observatory.

This committee has made preliminary studies and recommendations in regard to the handling of the budget and other financial problems, the merger or correlation of the various service facilities of

the two observatories, and the educational program to be set up at the California Institute. These plans envisage the initiation of graduate instruction in astrophysics in the fall of 1948. Attention has also been given to procedures for the most effective use of the greatly increased facilities which will become available with the completion of the instruments at the Palomar Mountain Observatory. In particular, proposals are under consideration by which observing time that is not required by the staff of the Palomar Mountain and Mount Wilson Observatories may be made available to competent observers from other institutions on the most effective co-operative basis.

Notable among the scientific results of the year's work is the discovery by H. W. Babcock of general magnetic fields in a number of early-type stars. The strengths of the fields at the poles of the stars investigated range up to 5500 gauss. For several decades local magnetic fields of similar strength have been measured in sunspots, and a general magnetic field of 50 gauss or less has been suspected in the sun. The present investigation represents the first observation of magnetic fields in the more distant astronomical objects. The early-type stars investigated by Babcock are thought to have exceptionally high rotational speeds, and the large magnetic fields observed are probably connected in some way with this rotation. The discovery of these very large magnetic fields introduces a new and unexpected factor in the equilibrium of the atmospheres of these stars, and it is hoped that these results may point to a solution

of several outstanding problems in connection with these objects.

Another important project has been the search for the nucleus of our own galaxy. Such nuclei are observed at the centers of other galaxies, but the region in the center of our own galaxy is so obscured by dust clouds that the observation of the nucleus by ordinary means is impossible. Making use of the well known fact that terrestrial haze may be penetrated with infrared light when it is opaque to visual light, Stebbins and Whitford have investigated this central region of the galaxy with infrared light. For this purpose a special infrared photocell was mounted on the 60-inch telescope, which was held stationary while various regions near the center of the galaxy were allowed to drift past. The measurements of the infrared light incident on the photocell during this process point to the presence of the galactic nucleus at 326.5° galactic latitude.

Because of the great popular interest in astronomy, the Observatory has had, since its founding, a large and increasing number of visitors at its telescopes and other facilities on Mount Wilson. In line with the general policy of the Institution to give wide dissemination to its work, the Observatory has made every effort to allow the public to view its facilities and the results of its investigations in so far as this could be done without serious inter-

ference with the scientific operations of the Observatory. A significant advance in the method of handling visitors at the Observatory was made with the opening of the visitors' gallery in the dome of the 100-inch telescope on July 30, 1946. This glassed-in gallery permits large numbers of visitors to obtain a close-up view of the 100-inch telescope and the interior of the dome without interfering with the regular use of the instrument. In addition to the visitors' gallery, a small museum is maintained near by with a representative group of transparencies enlarged from photographs obtained with the 100-inch telescope and other instruments. These facilities, therefore, enable the general visitor to see the Observatory's largest instrument, which, of course, is used almost exclusively as a camera rather than as a visual telescope, and to see a representative group of photographs taken with it. The visitors' gallery and museum are open from 1:30 to 4:30 P.M. Mondays through Fridays, and from 11:00 A.M. to 4:30 P.M. Saturdays and Sundays. It is estimated that more than 100,000 visitors made use of the visitors' gallery during its first year of operation, with 2000 being handled in one day.

The last of the contracts for defense work was completed on September 1, 1946. Since that time, the whole efforts of our shops have been devoted to Observatory work.

STAFF AND ORGANIZATION

RESEARCH DIVISION

Solar Physics: Harold D. Babcock, Seth B. Nicholson, Joseph O. Hickox, Edison R. Hoge, Edison Pettit, Robert S. Richardson, Mary F. Coffeen, Elizabeth S. Mulders, Myrtle L. Richmond, Phyllis W. Veit, Irene Whitney.

Stellar Motions and Distances: Ralph E.

Wilson, A. Louise Lowen, Myrtle L. Richmond.

Stellar Photometry: Walter Baade.

Stellar Spectroscopy: Paul W. Merrill, Horace W. Babcock, Ira S. Bowen, Theodore Dunham, Jr.,¹ Milton L. Humason, Alfred H. Joy, Rudolph Minkowski, Roscoe

¹ On leave July 1, 1946—March 1, 1947.

F. Sanford, Olin C. Wilson, Sylvia Burd, Cora G. Burwell, Dorothy D. Locanthi, A. Louise Lowen, Barbara Olsen.

Nebular Photography, Photometry, and Spectroscopy: Edwin P. Hubble, Walter Baade, Milton L. Humason, Rudolph Minkowski, Alice S. Beach.

Physical Laboratory: Robert B. King.

Editorial Division: Paul W. Merrill, editor; Elizabeth Connor, assistant editor and librarian; Helen Stecki Czaplicki, secretary.

Alfred H. Joy has continued as Secretary of the Observatory throughout the year. In the first serious accident that has occurred in connection with the observing program of the Observatory, Dr. Joy was injured by a fall from the Casscgrain observing platform early in November 1946. His injuries required hospitalization for the following four months. Before the end of the present report year, however, Dr. Joy was able to assume his full load of duties, including his observing schedule.

Dr. Theodore Dunham, Jr., resigned on March 1, 1947, to carry out investigations in the field of biophysics. Dr. Dunham joined the staff in 1929 and has made studies of planetary atmospheres, stellar spectra, and interstellar lines. He has also made very large contributions to the instrumentation program of the Observatory. In particular, he was largely responsible for the design of the present very efficient coude spectrograph of the 100-inch telescope.

Mrs. Elizabeth S. Mulders resigned, effective March 15, 1947, after eighteen years' service at the Observatory. During this period she was engaged in studies in solar physics and in editorial duties. Her position was taken first by Mrs. Phyllis Veit and later by Miss Irene Whitney.

Dr. Roscoe F. Sanford represented the Mount Wilson Observatory at the celebration of the seventy-fifth anniversary of the founding of the Córdoba Observa-

tory, Córdoba, Argentina. He attended as guest of the Córdoba Observatory.

Dr. Walter S. Adams and Dr. Ira S. Bowen were appointed research associates of the California Institute of Technology. This is in harmony with the plan for the joint management and operation of the two observatories at Mount Wilson and at Palomar Mountain.

RESEARCH ASSOCIATES

Walter S. Adams, Pasadena; Sir James Jeans, Dorking, England; Henry Norris Russell, Princeton University; Frederick H. Seares, Pasadena; Joel Stebbins, University of Wisconsin.

Dr. Adams has continued his search for interstellar lines in high-dispersion spectra of stars of types O and B. In collaboration with Dr. Martin Schwarzschild, he has studied the behavior of a group of iron lines in the spectrum of η Aquilae throughout the period of its light-variation. During the past year the detailed investigation of the blue and ultraviolet spectrum of ν Sagittarii has been completed and prepared for publication by Dr. Adams and Dr. J. L. Greenstein, of the Yerkes Observatory.

Dr. Stebbins and Dr. A. E. Whitford have continued their important photometric studies during the summer of 1946 and the spring of 1947. These investigations include: the establishment of a definitive scale of magnitudes for the extragalactic nebulae; the measurement of the colors of nebulae; the extension of an accurate scale of visual stellar magnitudes down to the seventeenth magnitude; a continuation of the search for the galactic nucleus; and further six-color observations of variable stars.

TEMPORARY ASSOCIATES

Dr. Martin Schwarzschild, of Columbia University, spent several weeks at the

Observatory in the early summer of 1946. In co-operation with Dr. Baade he took an extensive series of plates of Messier 3 to study the type of changes in the periods of the cluster-type variables, and thus to investigate the equilibrium conditions in these objects. In a second investigation the excitation temperature, electron pressure, and density were determined from line intensities in the spectra of η Aquilae. When correlated with the radial-velocity measurements already made by Dr. Adams, these provide a basis for the theory of the atmospheric pulsations of this Cepheid variable.

During the summer of 1946, Dr. Louis C. Green, of Haverford College, carried out theoretical investigations of the f -values or oscillator strengths associated with the transitions from the lowest states of $Ca\ II$, 2S , 2D , and 2P to the s , p , d , and f continua.

Dr. Lawrence Aller, of the University of Indiana, in co-operation with Dr. Minowski carried out a photometric investigation of the spectrum of the planetary nebula NGC 7027, covering the range $\lambda\lambda 3700-9000$. With the aid of plates previously taken by Dr. Merrill, a study was also made of the chemical composition of six B stars.

Mr. W. C. Miller, of Pasadena, has continued his search for bright-line objects with the 10-inch telescope and objective prism. A result of special interest was the discovery of a ninth-magnitude nova in Sagittarius in May 1947. Mr. Miller has also taken many slit spectrograms, chiefly

of Be stars, with the 60-inch and 100-inch telescopes.

Dr. A. G. Mowbray, of Pasadena, has taken part in the spectroscopic observing with the 60-inch telescope in addition to obtaining a number of excellent objective-prism photographs with the 10-inch telescope.

INSTRUMENT DESIGN AND CONSTRUCTION

Design: Edgar C. Nichols, chief designer; Harold S. Kinney, draftsman.

Optical Shop: Don O. Hendrix, superintendent; Floyd Day, optician.

Instrument Shop: Albert McIntire, superintendent; Elmer Prall, instrument maker; Fred Scherff, Oscar Swanson, Albert Labrow, Donald Yeager, machinists; Harry S. Fehr, cabinet maker.

MAINTENANCE AND OPERATION

Office: Anne McConnell, bookkeeper; Dorothea Neuens, stenographer and telephone operator.

Operation: Ashel N. Beebe, superintendent of construction; Kenneth de Huff, engineer; Charles Dustman, janitor and relief engineer; Thomas A. Nelson, Boyd Thompson, Ralph Bennewitz, Stanley Baird, Eugene Hancock, night assistants; Emerson W. Hartong, truck driver and machinist helper; Anthony Wausnock, Margie Wausnock, Pauline Byers, Alexander Kochanski, stewards; Arnold T. Ratzlaff, Homer N. Joy, janitors.

Several of those whose names are listed above have been with the Observatory for only a part of the year. In addition, numerous temporary employees have assisted in construction and repair work.

OBSERVING CONDITIONS

Most of the season's precipitation of 42.05 inches fell in November and December. This included a storm on November 11 to 14 that brought 21 inches of snow, disrupted the power line serving

the Observatory for over a week, and closed the Mount Wilson road for several days. The total snowfall for the year was 25 inches.

Solar observations were made on 319

days between July 1, 1946 and June 30, 1947. The 60-inch telescope was used on 262 nights and the 100-inch telescope 267 nights during this period.

SOLAR RESEARCH

SOLAR PHOTOGRAPHY

Solar photographs were made on 319 days between July 1, 1946 and June 30, 1947, by Hickox, Hoge, Nicholson, and Richardson. The numbers of photographs of various kinds were:

Direct photographs	670
<i>Hα</i> spectroheliograms of spot groups, 60-foot focus	1,125
<i>Hα</i> spectroheliograms, 18-foot focus	1,284
K2 spectroheliograms, 7-foot focus	19,520
K2 spectroheliograms, 18-foot focus	1,204
K prominences, 18-foot focus	1,107

SUNSPOT ACTIVITY

The magnetic classification and study of sunspots and related phenomena have been continued by Nicholson, Mrs. Mulders, and Mrs. Veit. Co-operative programs have been carried out with the United States Naval Observatory, the Observatory at Kodaikanal, the Department of Terrestrial Magnetism of the Carnegie Institution, and the Central Radio Propagation Laboratory of the National Bureau of Standards.

During the calendar year 1946, observations were made on 334 days. No days were without spots, whereas in 1945 twelve days were without spots. The total number of sunspot groups observed was 416, compared with 220 in 1945. All belonged to the new cycle, no spots belonging to the old cycle having been observed since August 8, 1945. In the new cycle the number of groups in the northern hemisphere increased from 71 in 1945 to 200 in 1946; in the southern hemisphere from 141 to 216.

The monthly means of the number of groups observed daily during the past

two and one-half years are given in the accompanying table.

MONTH	DAILY NUMBER		
	1945	1946	1947
January.....	2.5	4.2	9.9
February.....	1.1	7.7	10.5
March.....	1.9	6.7	11.8
April.....	2.8	7.1	11.5
May.....	3.6	7.2	16.8
June.....	3.8	7.3	13.4
July.....	4.4	8.2	...
August.....	2.8	8.5	...
September.....	3.6	8.9	...
October.....	5.7	9.8	...
November.....	5.1	9.8	...
December.....	2.9	8.5	...
Yearly average ...	3.4	7.8	...

Last year a huge sunspot group which appeared in February 1946 was reported as the largest ever photographed. Another very large group with about the same maximum area was on the sun from February 5 to May 7, 1947. When it crossed the sun's disk in March, the group contained the largest single spot ever photographed. In April the group as a whole was larger than in March, being then fully as large as the great group of February 1946. Another large group, the third largest on record, was on the sun in July 1946. The number of sunspot groups observed daily in May 1947, 16.8, set a new record for Mount Wilson. The relative sunspot numbers compiled at Zürich indicate that sunspots were more numerous in May 1947 than in any other month since 1749 with the exception of May 1778. Whether this great activity in May will

mark the maximum of the present cycle cannot be known for some months. It seems almost certain, however, that the century-long series of alternating high and low cycles has been broken, because this cycle, which should have been a low one in that series, has already exceeded the maximum of the last cycle.

SUNSPOT POLARITIES

Magnetic polarities in each spot group have, so far as possible, been observed at least once. The classification of groups observed between July 1, 1946 and June 30, 1947 is indicated in the accompanying table. "Regular" groups in the northern hemisphere are those in which the preceding spot has S (south-seeking) polarity and the following spot N polarity; in the southern hemisphere the polarities are reversed.

HEMISPHERE	REGULAR	IRREGULAR	UNCLASSIFIED
North.....	175	7	92
South.....	205	6	85
Whole sun.	380	13	177

FLARES

The spectra of bright flares have been studied on plates taken with the 75-foot spectrograph by Nicholson and Richardson. A total of 212 emission lines have been identified; they arise from 17 neutral and singly ionized atoms. The Balmer series can be traced in emission to H₂₁ at $\lambda 3679$. The relative intensities of the flares photographed at Mount Wilson have been compared with those observed by C. W. Allen at Canberra. In most cases, the relative intensities of the lines correspond as closely as could be expected, but many striking exceptions occur, indicating that

flares of about equal brightness do not necessarily have identical spectra.

Photographs have been obtained of H β and H γ in the spectra of solar hydrogen "bombs." The bombs appear as bright extensions to the red and violet in the hydrogen lines over active spot groups. If the widening of lines in the Balmer series produced by the bombs is due to Stark effect, the extensions should be greater in H γ than in H β , since Stark effect increases with decreasing wave length. Preliminary results show the widening to be roughly the same in photographs of the two lines taken simultaneously. Up to date, however, no observations have been made under first-class conditions.

PROMINENCES

The photographs of the eruptive prominence of June 4, 1946 have been measured and reduced by Pettit. This prominence was ejected from the earthward face of the sun in latitude S 48° with velocities of 136 and 312 km/sec. When the measures are corrected for the angle of projection they indicate that this prominence reached the unprecedented elevation of 1,703,000 km, or 1.22 solar diameters above the sun. The highest previous record was 1,550,000 km, for the eruptive prominence of March 20, 1938, also observed at Mount Wilson. An interesting feature of the motion of the prominence of June 4, 1946 is that it was accomplished with two velocities in a gravitational field that varied from four-tenths to one-twelfth of that at the solar surface. The prominence was one of the largest ever observed.

Eruptive prominences were photographed also on September 15, 1946 and April 14, 1947, the one on the latter date rising from the vicinity of a great sunspot on the west limb.

An effort is being made to obtain measurable series of photographs of interactive and tornado prominences, in order to study the exchange of gases between two neighboring prominences and to obtain more data on rotary motions.

THE SOLAR SPECTRUM, $\lambda 6600$ TO $\lambda 13495$

Under the foregoing title, Carnegie Institution of Washington Publication 579, by Harold D. Babcock and Charlotte E. Moore, is now in press. The major portion (67 pages) of this volume consists of a table of the wave lengths, intensities, and identifications of about 7350 lines observed in the solar spectrum in the wave-length range mentioned in the title. The 26-page text discusses instruments used, the intensities of disk and sunspot spectra, identifications and excitation potentials, comparisons between solar and stellar spectra, elements present, etc.

GENERAL MAGNETIC FIELD OF THE SUN

Various sources of error in the method adopted for the study of weak solar magnetic fields have been studied in detail by H. D. Babcock with the assistance of Mrs. Coffeen. Personal errors in micrometer settings on the interference fringes from the Lummer plate, relative errors presented by alternative methods of reducing the observations, properties of some circular analyzers, and other technical details have been included.

Observations made like those of the general field, except that a small single sunspot is held centrally on the window of the Lummer plate, are used for testing the performance of the entire optical train. When the effective magnetic field is weak, as in these tests, the measurability of the spectrum lines is fully comparable to that in observations of the general field. It thus appears that the definitive observa-

tions are adequate for detecting a general field whose polar intensity (under usual assumptions) is 13 gauss, or about one-fourth of the maximum value reported by other workers.

Visual observations have been made with a modified method of observing weak magnetic fields, utilizing either a Lummer plate or a Fabry-Perot interferometer. Some merits and some disadvantages are found in comparison with the photographic method long in use here, and further study is required. This visual method rests upon small variations of intensity, rather than of position, among the interference fringes of selected lines in the solar spectrum.

ULTRAVIOLET SOLAR SPECTRUM

Recent reports of the extension of the ultraviolet solar spectrum, through observations with low dispersion from high-altitude rockets, give additional interest to spectrograms made at ground level. Attempts have been made during the current year by H. D. Babcock to improve the data mentioned in earlier reports in the range $\lambda 2914$ to $\lambda 3060$. Because of poor observing conditions in Pasadena, however, only minor additions have been made. All the available data in this wave-length range are being prepared for publication in collaboration with Dr. Charlotte E. Moore, of the National Bureau of Standards.

SOLAR CURVES OF GROWTH

A study of empirical curves of growth for lines of neutral vanadium ($V I$) in the solar spectrum has been made by R. B. King in collaboration with Dr. K. O. Wright, of the Dominion Astrophysical Observatory, Victoria, British Columbia. Solar equivalent widths, obtained principally from the Utrecht *Atlas*, and *gf*-

values obtained in the laboratory were used to construct the curves. A mean excitation temperature of about $5400^{\circ} \pm 200^{\circ}$ K was found for $V\ 1$. This may be compared with temperatures of about 4400° and 4900° obtained previously by similar methods for solar $Ti\ 1$ and $Fe\ 1$ lines, respectively. A condition commonly ascribed to turbulence in the solar atmosphere (in addition to ordinary thermal agitation of the atoms) was exhibited by the curves of growth for lines arising from the lowest energy levels. The magnitude of this effect corresponds to mean turbulent velocities of about 3 km/sec for lines arising from the ground state; it decreases with increasing excitation potential of the lines. The effect is similar to that found by Wright in curves of growth for lines of $Fe\ 1$ in F-type stars.

ABUNDANCE OF OXYGEN IN THE SUN

With the aid of a new determination of the wave lengths of the forbidden $O\ 1$ lines at $\lambda 6300\text{\AA}$ and $\lambda 6363\text{\AA}$, Bowen has been able to identify these lines as well as the forbidden $O\ 1$ line at $\lambda 5577\text{\AA}$ with weak solar absorption lines. Since these lines are all transitions from very low terms in the oxygen atom, their equivalent widths can be used for the determination of the abundance of oxygen in the sun without the use of the very large and uncertain

Boltzman-factor correction that has been necessary in previous determinations. Measurements of the equivalent widths of these solar absorption lines gave the amount of oxygen present in the reversing layer as 7×10^{20} atoms, or 18 mg, per sq. cm. A comparison of the equivalent widths of these lines with the widths of the high-level permitted lines in the infrared yielded an excitation temperature for oxygen of 5200° .

SOLAR ABSORPTION COEFFICIENTS

Preliminary measurements of the distribution of violet light across the sun's disk have been made by Nicholson in an effort to determine whether short-period fluctuations can be detected in the solar absorption coefficients. Drift-curves have been obtained on about 100 days. Their measurement and reduction are in progress with the assistance of Miss Richmond and Mrs. Veit.

RELATION BETWEEN SOLAR AND TERRESTRIAL PHENOMENA

Nicholson has co-operated with Dr. Oliver Wulf, of the United States Weather Bureau, in the study of solar and terrestrial relations, particularly with regard to ionospheric changes induced by variations in terrestrial magnetism.

PLANETARY INVESTIGATIONS

Positions of Jupiter's satellites J VI, VII, VIII, IX, X, and XI were measured by Nicholson on photographs made with the 60-inch and 100-inch reflectors. The United States Naval Observatory is determining the positions of all the comparison stars used in measuring photographs of Jupiter's satellites since 1938. The

re-reduction of the satellite plates and the remeasurement of many of them have been started at Mount Wilson. When completed, this program will give positions of Jupiter and its satellites referred to the same co-ordinate system. Miss Richmond is assisting in the measurement and reduction of the photographs.

STELLAR INVESTIGATIONS

PHOTOELECTRIC PHOTOMETRY

Stebbins and Whitford made six-color observations of the typical variable stars η Aquilae and RR Lyrae, similar to the previous measures of δ Cephei and Polaris. In both the new series the same phenomenon, a retardation of phase with increasing wave length, was found as in δ Cephei. In addition, the correlation of the colors with the varying spectral types will throw new light on the processes of these pulsating stars. Incidentally to the program on nebular photometry, the photo-visual magnitudes in two Selected Area fields were calibrated photoelectrically down to the seventeenth magnitude.

VISUAL MAGNITUDES OF NOVAE

The measures of the visual light of T Coronae Borealis have been continued by Pettit. T Coronae is the only fast nova for which a pronounced secondary maximum has been observed. The star, which rapidly faded from its initial observed brightness of 3.2 mag. in February 1946 to 9 mag. in March, reached primary minimum 9.9 mag. in May, began to brighten in the last week of May, and reached 7.8 mag. in June and July, after which it declined slowly, and in July 1947 is about magnitude 9.8. The recent light-curve of T Coronae is everywhere nearly the same as that of its outburst in 1866, with a possible general depression of 0.1 to 0.2 mag. Several recrudescences of a few tenths of a magnitude in light were observed, notably in October 1946 and March 1947. The primary minimum, corrected for the M-type companion, was 11.0 mag.

Photographs of the star field have been made with the 60-inch telescope with local color filters for T Coronae which trans-

mit red and blue light for the determination of any shift due to the presence of the companion.

The visual light of Nova Puppis, measured on two nights, declined 0.42 mag. during the year, only about half as much as during the previous year.

VISUAL MAGNITUDES OF DOUBLE STARS AND VARIABLE STARS

Measures of the magnitudes of double stars with faint close companions were continued by Pettit with the wedge photometer attached to the 60-inch telescope. One hundred and twenty measures of double-star systems were made during the year, and measurements on 51 systems have now been completed on three or more nights since this program was started.

Measures of the visual light of HC Herculis, an RV Tauri type star, were made over the period July to November 1946. These measures show that the principal minima occurred on August 9 and October 22, seven days after the dates predicted by Waterfield's formula. The magnitudes at principal maximum and minimum were 6.8 and 8.5, about half a magnitude brighter than the catalogue values.

ANGULAR DIAMETER OF STARS FROM OCCULTATIONS BY THE MOON

During the summer of 1946 Whitford increased the number of occultations observed from the single one previously reported to a total of four. The calculated angular diameters ranged from 0''.008, for the first case of ν Virginis, to 0''.008 for the A₉ star 44b Ophiuchi. The intensity patterns observed as the edge of the moon's shadow swept across the tele-

scope agreed with those expected from the simple knife-edge diffraction theory, and confirmed the view that the method is

applicable to the determination of the angular diameter of stars in the range from $0''.002$ to $0''.020$.

STELLAR SPECTROSCOPY

RADIAL VELOCITIES

Observatory program. For about thirty years the Observatory has carried on observations to determine the radial velocities of stars in several categories, the five principal ones being: (1) the stars of the later spectral classes listed in the *Boss Preliminary General Catalogue*; (2) all stars with proper motions exceeding $0''.1$ per year; (3) stars in Kapteyn's Selected Areas; (4) stars in the four clusters Taurus, Pleiades, Praesepe, and δ and χ Persei; and (5) a selected list of double stars. For those stars visible during the seasons when good observing conditions prevail, the observations are essentially complete. Unpublished radial velocities are available for about 1000 stars, and a sufficient number of plates have been obtained for about 750 others. About 600 plates of 325 stars are needed and must be obtained mainly during the seasons when bad observing conditions prevail. It is hoped that these programs may be completed with the 60-inch telescope during the coming year.

During the past year, in which observing conditions were definitely subnormal, 880 spectrograms were obtained with the 60-inch, 580 on the general radial-velocity programs and 300 in connection with special investigations.

The rapid accumulation of radial velocities since the publication of the Lick catalogue in 1932 makes it desirable from the standpoint of the student of stellar motions that the list be brought up to date. R. E. Wilson, with the assistance of Miss Richmond, has undertaken this compilation and during the year has made a

card catalogue of all known radial velocities which contains some 11,750 entries.

Dwarf stars. The radial velocities and spectral types of 180 dwarf stars with proper motions greater than $0''.35$ per annum were published by Joy. The list includes 110 dM-type stars, some of which are of the lowest luminosity thus far observed for radial velocity. Twenty-one subdwarfs, for which the mean radial velocity is 121 km/sec, were recognized. Three or more plates were available for practically all the stars. The probable error of the adopted velocity lay between 1 and 2 km/sec for most of these stars. With the aid of absolute magnitudes determined from trigonometric parallaxes, a table was constructed showing the correlation between absolute magnitude and spectral type from dK4 to dM6. Emission lines of H and Ca II were observed in 41 stars of types M1.5 or later, and it was noted that in subdwarfs emission lines are extremely weak or absent.

LONG-PERIOD VARIABLE STARS

Omicron Ceti. Measurements of coude spectrograms of the long-period variable \omicron Ceti, taken by Merrill and Joy from 1934 to 1947, indicate that the mean radial velocities based on the absorption lines vary by a few kilometers per second at different maxima, and also that the curves of velocity variation are subject to considerable changes in shape and range from cycle to cycle.

As a test of the hypothesis that the deformation of the emission lines at certain phases is due to line absorption by overlying atoms of the reversing layer in

the star, 62 lines within a distance of one angstrom from the centers of 28 hydrogen emission lines were measured by Joy on 88 high-dispersion spectrograms and were identified with lines of elements commonly found in absorption in low-temperature stars. The probability of the occurrence of these lines was strengthened by noting the presence in α Ceti of other members of the multiplets to which they belong. The iron lines show the same correlation between ionization potential and velocity displacement found for iron lines falling outside the regions of hydrogen emission. By comparing the wave lengths, four lines measured within the $H\gamma$ emission were attributed to titanium oxide.

Variables of class N. Observations made by Sanford during the past year and those already accumulated now give sufficient coverage of all phases of eight long-period variables of spectral class N to show a definite velocity variation. The velocity in general is highest between minimum and maximum and lowest between maximum and minimum. Present in most of them as a strong emission line at or near maximum light, $H\alpha$ is exceedingly weakened or absent at and near minimum light. Changes in the continuous spectrum between maximum and minimum light are marked in the region $\lambda\lambda 5800-6700$ in some of these variables; in other variables there are changes in the strength of such absorption lines as D_1 and D_2 of Na .

Variables of class Se. Stars whose spectra are characterized by bands of zirconium oxide have long been recognized as forming one of three parallel branches of giant red stars at the cool end of the stellar temperature sequence. Many years ago the spectra of these stars (class S) were described in Mount Wilson Contributions Nos. 252 and 325. During the past year Merrill has carried out extensive studies

of the intricate spectra of two well known variable stars of class Se by means of spectrograms with the relatively high dispersion of 10 Å/mm. These studies were comparable with those of Me variables made in the preceding year.

In the spectrum of R Andromedae, measures of more than 1300 dark lines served as a basis for a detailed survey of the multiplets of nearly 30 elements. The displacements of lines of neutral atoms (and probably also of ionized atoms) have a persistent positive correlation with excitation potential. Lines of ionized atoms have positive displacements with respect to lines of neutral atoms. The mean velocity from the dark lines exhibited little variation with phase over a postmaximum interval of about 100 days.

Atoms of yttrium and zirconium appear to be more abundant in R Andromedae than in Me variables. This tentative conclusion, if confirmed by quantitative photometric analysis, might guide us toward the cosmological interpretation of the trifurcation of the low-temperature end of the stellar sequence.

In the investigation of χ Cygni, many new data were recorded concerning the behavior of bright lines during the postmaximum phase of the light-cycle. A two-night exposure with the 100-inch telescope, when the variable, at magnitude 11.4, was 162 days after maximum, brought out nearly 300 bright lines. The total number of bright lines studied was about 400. Most of these are due to hydrogen or to metals (either neutral or singly ionized), but some of them, including a few strong ones, have thus far resisted all attempts at identification. A peculiarity of physical interest is the inordinately high intensity of bright lines from certain atomic levels. These levels appear to be energized by line coincidence—a specialized process far removed from thermal equilibrium. A

new example in the zirconium spectrum was detected by Bowen.

Since the bright-line spectrum undergoes remarkable changes with phase, becoming more interesting as the light of the variable star declines, it is hoped in the future to obtain additional spectrograms still closer to minimum.

ECLIPSING VARIABLE STARS

Spectroscopic observations by Joy during the total eclipses of RW Tauri showed remarkable changes in the intensity of the emission lines emanating from the gaseous ring around the B₉ component. On account of its small size, the ring can be observed only at second and third contacts. At 15 eclipses emission of widely varying intensity was observed on one or both limbs, but at 5 eclipses no emission appeared. The ring is evidently quite irregular in structure. The velocities remain constant at about 350 km/sec, but the gases may be distributed in the form of clouds or spiral streamers. S Cancri was observed at minimum for determining the velocity changes of the secondary star.

O. C. Wilson has nearly completed his investigation of the 1939-1940 eclipse of ζ Aurigae. The results should be ready for publication in the near future.

VARIABLE STARS OF OTHER TYPES

Joy has continued the observation of certain groups of variable stars for the purpose of supplying spectroscopic material for a study of the physical characteristics and motions of the different classes of variables. Spectrograms of stars of the RR Lyrae, RV Tauri, SS Cygni, and R Coronae Borealis classes and of the brightest variables in the globular clusters were obtained at suitable phases. Addi-

tional observations of AE Aquarii were made to test the constancy of the period of velocity variation.

In continuation of work begun in preceding years, Sanford, using the 32-inch camera of the coude spectrograph, has obtained spectrograms of the variable RR Lyrae; a half-dozen Cepheids, including TU Cassiopeiae with the period 2.1 days, one of the shortest known; and T Monocerotis with a period of 27 days. A start was made on observations for the velocity-curve of SV Vulpeculae, a Cepheid with one of the longest periods known, 45 days.

Eta Aquilae. A series of 18 high-dispersion spectrograms of η Aquilae taken throughout the period of light-variation has been measured by Adams in collaboration with Dr. Martin Schwarzschild. Special attention has been given to a list of 42 iron lines selected to provide a considerable range of intensity and excitation potential.

Nova T Coronae Borealis. Spectrograms of Nova T Coronae Borealis with dispersions of 10 Å/mm in the blue and 20 Å/mm in the red have been obtained by Sanford each month except October, November, and December 1946, when it was too close to the sun. Many changes in emission line structure and in the shell spectrum have been found, and the measurements have been completed. These measures have yet to be sifted and brought into orderly sequence. The lines belonging to the class-M spectrum in this long series of spectrograms show a velocity variation with a period between 200 and 300 days. Definite evaluation of this period should be possible at the end of the 1947 observing season.

SPECTROGRAPHIC STUDIES OF SPECIAL STARS

Wolf-Rayet stars. O. C. Wilson has continued his survey of the spectra of

Wolf-Rayet stars with the following preliminary results:

The star HD 50896 has shown shifts of considerable magnitude in the positions of some of the emission bands. No secondary spectrum is visible, and it is not yet known whether the star is a binary or not. BD+40°4220 has an Of-type spectrum and is probably a spectroscopic binary of considerable range with both spectra visible. The star is extremely red for its type. HD 190918 is a Wolf-Rayet star with well marked absorption lines. Observations of the absorption spectrum have shown that the star is a spectroscopic binary. A tentative period of about 82 days has been derived. HD 193793 also is a Wolf-Rayet star with absorption lines, although of poorer quality than those in HD 190918. Observations of the absorption spectrum indicate that the star is probably a spectroscopic binary, although no period has been found.

Be stars. Considerable progress has been made during the year by Merrill, Burwell, Miller, and Mowbray in the discovery and observation of bright-line stars. The survey with the 10-inch telescope is nearly complete for low galactic latitudes; certain areas at higher latitudes are now being photographed. A ninth-magnitude nova was discovered in May 1947. Scores of additional Be stars, detected in the objective-prism survey, are awaiting observation with a slit spectrograph. A number of stars with interesting spectral changes have been found.

Upsilon Sagittarii. Dr. J. L. Greenstein and Adams have prepared for publication the results of a detailed investigation of the spectrum of υ Sagittarii in the region $\lambda\lambda 3564-4861$. Approximately 1000 lines have been measured on two spectrograms of high dispersion. In addition to many elements which would be expected, there is considerable evidence for the presence

of Cl II and Fe III, and some possibility of P II and C II; S II is strongly represented, but C I and He II appear to be absent. An interesting discovery is the doubling on two of the spectrograms of a considerable number of lines of ionized elements, more especially of Fe II.

GENERAL MAGNETIC FIELD OF EARLY-TYPE STARS

The initial work on general magnetic fields in stars was reported a year ago. Since that time, a survey of likely stars down to the sixth magnitude has been continued by H. W. Babcock with the aim of discovering those that have strong fields. Also, a more detailed study of the Zeeman effect in a few stars, using the highest available dispersion, has been begun. Magnetic fields stronger than 1000 gauss have been observed in γ Equulei, β Coronae Borealis, BD-18°3789, and probably two or three others, in addition to γ Virginis. The polar field of the "europium star," BD-18°3789, is about 5500 gauss the strongest yet measured. Several other stars, plates of which have not yet been fully measured, probably have fields of somewhat less than 1000 gauss. A considerable body of evidence now bears out the reality of the effect, and there are no discordant observations. Several stars observed with the analyzer show no discernible Zeeman effect. This group includes α Canis Majoris (Ao), α Canis Minoris (F5), ϵ Pegasi (Ko), and α Tauri (K5). The results so far obtained suggest that strong magnetic fields are a general property of the metallic-line stars of type A, and particularly of the spectrum variables which are a subgroup of this type. The apparent correlation of magnetism with spectrum variability deserves much further study. Consideration of the curve of growth suggests that the Zeeman effect should

increase the equivalent widths of moderate and strong absorption lines; this effect will probably have to be taken into account in studies of the abundances of elements in the early-type stars.

The discovery of magnetism in selected stars (which in all probability are in rapid rotation) has implications that may be of significance as regards the relation between the magnetic and mechanical properties of large rotating masses. In this connection, Babcock has pointed out that the magnetic moments of the earth, the sun, and γ Virginis (8×10^{26} , 8.4×10^{33} , and 4×10^{36} gauss cm³, respectively) are at least roughly proportional to their angular momenta, and may be obtained, in each object, by multiplying the angular momentum, in c.g.s. units, by 10^{-15} . This relation may be of fundamental significance, but it should still be regarded with reserve, since the obliquity of the magnetic axes of the earth and of the sun has not yet been explained.

If the proportionality of magnetic moment to angular momentum is a universal law of large rotating masses, it is possible that it is also applicable to a rotating stellar system such as our galaxy or an extragalactic nebula. It then becomes possible to compute the magnetic moment of such a system. For the galaxy and for the Andromeda nebula, one finds a magnetic moment of roughly 10^{59} gauss cm³, or a corresponding magnetic field of about 10^{-8} gauss in the plane of the system, the lines of force being perpendicular to the plane.

The controlling effect exerted by the magnetic field of a rotating star on ions and electrons in or beyond its atmosphere may well have considerable interest as regards the support of equatorial rings of tenuous material, and possibly even as regards theories of the cosmogony of planetary systems and double stars.

INTERSTELLAR LINES

In a search for faint components of the interstellar H and K lines, measurements have been completed by Adams for about 300 stars of types O and B. About 40 per cent of the stars observed show one or more components to the principal line. With few exceptions, the stars showing the most complex lines are found in the lowest galactic latitudes. The analysis of the material is in progress.

Interstellar lines are probably formed in relatively thin curtains stretched at irregular intervals between the stars. Lines whose intensities increase (statistically) with distance should be distinguished from lines which show no dependence on distance. Comparison by Merrill and O. C. Wilson of the components of the *Ca II* and *Na I* lines in a number of stars suggests a dependence of ionization on the thickness of the clouds, the thin curtains being the more highly ionized. Consideration should be given to those conditions (of liquefaction or of chemical combination) under which interstellar atoms may be removed from the state in which they can give rise to atomic lines.

GALACTIC NEBULAE AND STAR CLOUDS

PLANETARY NEBULAE

Minkowski has identified 35 new planetaries during the past year, bringing to 111 the total number found in the survey prior to July 1, 1947. The survey is virtu-

ally complete between galactic longitudes 0° and 205° , but a number of objects in the direction of the galactic center still remain to be investigated.

A large number of spectrograms on

infrared- and red-sensitive plates have been obtained by Minkowski for the spectrophotometric study of NGC 7027 undertaken with L. Aller. The observational program has been completed and the reduction of the material is under way.

The survey by O. C. Wilson of the brighter planetary nebulae with a dispersion of 10.4 Å/mm has continued during the year and is near completion. The results in general confirm those reported earlier.

TRANSPARENCY OF THE ORION NEBULA IN THE INFRARED

Since earlier plates suggested that the Orion nebula might be quite transparent for still longer wave lengths, Baade has made a check in the near infrared. The selected region ($\lambda\lambda 7100-7500$) contains only a few weak emission lines, and the light of the nebula is largely suppressed on the photographs. The results are very striking. The area normally filled with the luminous nebulosity is replaced by a corresponding area of high stellar density, far above that of the surrounding region. Obviously the transparency of the Orion nebula for long waves is not restricted to the neighborhood of the exciting stars where it was first noticed (Trapezium cluster), but is characteristic of the whole of the excited nebulosity. The transparency decreases with increasing distance from the exciting stars.

VARIABLES IN THE NUCLEAR REGION OF THE GALACTIC SYSTEM

Baade has continued the search for variables in the field around the globular cluster NGC 6522 ($\lambda = 328^\circ$, $\beta = -4^\circ$). Although only occasional plates have been blinked during the year, the number of recognized variables in the field has increased to 200, corresponding to 540 per square degree. The observations will be

continued until the type of variability has been ascertained for most of the variables.

SEARCH FOR THE NUCLEUS OF THE GALAXY

Dr. Stebbins and Dr. Whitford continued the search for the nucleus of our galaxy, using a band of infrared radiation at effective wave length 10300 Å. With a photocell and suitable filter on the 60-inch reflector, the sky was allowed to drift with the diurnal motion across the field of a focal diaphragm 8½ in diameter. As the intensity along each sweep was recorded, the star clouds and individual stars interfered somewhat but did not wholly prevent penetration to the background. The area of the search extended about 2° on each side of the galactic equator from longitude 321° to 331° , with intensive coverage within 1° of the equator, and with supplementary sweeps of greater extent at selected points. The sweeps at successive longitudes usually gave maxima near the galactic circle, outlining a bulge extending about 8° in longitude and 4° or 5° in latitude, with center near $326^\circ.5$.

Concurrent sweeps in the red at wave length 7190 Å gave a color excess on the red-infrared scale of +1.5 mag., equal to that of the most strongly reddened B stars in the sky. It is shown that the radiation cannot come from a mixture of star clouds and absorbing material like that within one or two kiloparsecs of the sun, but must come from a more luminous object behind absorbing material. The light of the bulge, with maximum apparent photographic surface brightness of 25.4 mag./sq. sec., adds up, when corrected for absorption, to a total quite comparable with the light of an equal section of the Andromeda nebula. That the observed bulge is probably near the galactic center is shown by its position, form, color, and total light.

EXTRAGALACTIC NEBULAE

PHOTOELECTRIC MAGNITUDES AND COLORS

Dr. Stebbins and Dr. Whitford each spent two months at Mount Wilson, measuring photoelectric magnitudes and colors of nebulae and faint stars. The results form the most significant contribution to the photometry of nebulae that has been made up to the present time. The results may be summarized as follows:

1. Photoelectric magnitudes of more than 150 nebulae were measured, ranging from about $m = 9$ to 18, and distributed over the entire sequence of classification. Apertures used were large enough to include the entire nebula as recorded on photographs. Because the technique is inherently accurate and free from systematic effects, the data establish a definitive scale of nebular magnitudes down to limits of size and brightness well within the range suitable for measurement by photographic methods (jiggle camera, extrafocal images, etc.). In particular, the data serve to calibrate the Shapley-Ames estimated magnitudes of all nebulae brighter than the thirteenth magnitude and the fainter magnitudes used in the formulation of the law of red-shifts.

2. Colors, red and blue, were measured for about 75 of the nebulae, also distributed over the sequence of classification. The systematic decrease in color indices along the sequence, suggested by previous investigations, was confirmed and placed on a quantitative basis. The data thus establish a correlation between integrated color and type of stellar population. The phenomenon was further investigated by measures of the distribution of color over the images of several very large, intermediate-type spirals. These spirals are transition cases between systems of pure

type II (elliptical nebulae) and systems of pure type I (late spirals); and the segregation of types indicated by the color distribution is an important datum in discussions of stellar evolution.

An extensive investigation of colors of elliptical nebulae emphasized the remarkable homogeneity of the group, and established, quantitatively, the relation between color and absolute magnitude (color indices increase with luminosities). Measures of the several brightest elliptical nebulae in the clusters, Virgo, Coma, Corona Borealis, and Boötes (one nebula only), for which red-shifts are available indicated a correlation between color and red-shift according to which the color index increased by 0.4 mag., as the red-shifts ranged up to $d\lambda/\lambda = 0.13$.

3. Colors and magnitudes were measured for 21 stars in Selected Area 57, ranging from magnitude 12.6 to 17.1, and for 34 stars in Selected Area 61, ranging from magnitude 10.1 to 16.8. Connections with the polar sequence insure that the colors and the zero point of the new magnitudes lie in the International System. These data furnish a definitive check on the current photographic scale in the two areas down to about the seventeenth magnitude, and thus provide reliable zero points for the faint extension of the scales (from magnitude 16 to 21) previously established by Baade. This extension represents the photometric standards used in the large-scale explorations of the universe.

Furthermore, the color measures provide a new, reliable scale of photovisual magnitudes which can be readily extended to the limit of the 100-inch telescope in one photographic step (i.e., without the necessity of piecing together successive steps—the process which has introduced most of the uncertainties in pre-

vious fundamental photometry). The data also furnish an approximate scale of red magnitudes, subject to uncertainties of the order of 0.1 to 0.2 mag., because of the short color base line used in the actual measures. A red scale is especially urgent for cosmological studies, which involve the effects of red-shifts ranging up to 1000Å or more. In order that the shifted radiation under investigation may come from a well known region of the unshifted spectrum, it is desirable that the investigations be made in the red. The procedure is now practical, because of recent improvements of red-sensitive emulsions, but it cannot provide quantitative data until an accurate scale of red magnitudes is available. The new data represent a first step toward the establishment of the required scale.

BRIGHTEST STARS IN EXTRAGALACTIC NEBULAE

Hubble has measured the brightest stars in about 80 spirals and irregular nebulae, on the definitive scale of magnitudes established by Baade in Selected Areas 57 and 68. The program includes nebulae in clusters, groups, and the general field, and the magnitudes extend down to about 20 and 21 with the 60-inch and 100-inch telescopes, respectively.

The data furnish a revised luminosity function of brightest stars based primarily upon a complete survey of the central region of the Virgo cluster down to nebular magnitudes about 15.5, and reinforced by data from nearer groups reduced to the same distance by means of red-shifts. Provisional results suggest that the mean value of brightest stars in the Virgo cluster is about $m_{pg} = 20.2$, with a range of the order of 1.5 mag. in either direction. The fainter limit is beyond the reach of the 100-inch, but the estimate is partially controlled by the fact that the number of

faint, unresolved, late-type spirals is comparable with the number of those to be expected among the superposed nebulae in the general field. The corresponding value of the mean absolute magnitude, about -6.5 , will not be much improved until Cepheids have been observed in a more representative collection of spirals than that available at present.

The data clearly indicate that the luminosity of the brightest stars in a nebula increases with the luminosity of the nebula, i.e., with the size of the sample. Since the ranges in the two quantities, M_s and M_n , are widely different (3 mag. and 6 mag., respectively), it is possible to express the data as a correlation between M_s and the difference, $(M_s - M_n)$, or its equivalent, the directly observable quantity $(m_s - m_n)$. This procedure reduces the dispersion in estimates of distances of isolated field nebulae and of groups in which only a few of the brighter members can be resolved.

MOTION OF THE GALACTIC SYSTEM WITH RESPECT TO THE NEARER EXTRAGALACTIC NEBULAE

The improved distances have been used in an investigation of the motion of the galactic system with respect to the resolved nebulae outside the local group. When the known effects of the galactic rotation and red-shift are removed from radial velocities, the data suggest a motion of the general order of 200 km/sec, in the general direction of $\lambda = 170$, $\beta = +25$. Because of the particular location of the galactic system, only small fractions of its motion are reflected in the observed radial velocities of the other members of the local group, and they do not seriously alter the pattern of internal motions within the group as suggested by the uncorrected data.

SURVEY OF THE ANDROMEDA NEBULA

Baade's survey of the south-preceding outer region of the Andromeda nebula out to $2^{\circ}5$ from the nucleus, in the ultra-violet, blue, red, and near infrared, has been practically completed. Of particular interest is an emission nebulosity found on the major axis, about $114'$ from the nucleus. It is the outermost emission object thus far identified. Humason has obtained an excellent spectrum of this nebulosity, using a dispersion of 230 \AA/mm at $H\gamma$; the radial velocity, $-497 \pm 10 \text{ km/sec}$ (from 10 lines), indicates that, at this distance from the nucleus, differential rotation (Kepler motion) prevails. The new velocity, since it is the first to be recorded in the Keplerian branch of the rotation-curve, furnishes a much improved estimate of the mass of the spiral, namely 1.0×10^{11} suns. This value represents the material less than $114'$ from the nucleus, but the material at still greater distance presumably would represent an almost negligible fraction of the total.

IMPROVED VELOCITIES OF MEMBERS OF THE LOCAL GROUP

Humason has also obtained spectra of emission patches in three other members of the local group, with the same dispersion (230 \AA/mm at $H\gamma$), on each of which it was possible to determine radial velocities from 7 or 8 lines with probable errors of 5 to 8 km/sec. These improved velocities (-343 and -235 for IC 10 and IC 1613, respectively, and -30 and -34 for two patches in NGC 6822) confirm the assignment of IC 10 to the local group and re-emphasize the absence of red-shifts within the group.

SPECTRA OF EXTRAGALACTIC NEBULAE

Humason has continued the work of preparing for publication the data derived

from spectra of more than 500 nebulae observed at Mount Wilson. Spectral types have been re-estimated on a uniform system, relative weights assigned, probable errors investigated, and some 20 nebulae reobserved in order to remove gross uncertainties and improve assigned weights.

The spectral types (representing the nuclear regions) vary systematically through the sequence of classification from mean values of G2.9 for 164 elliptical nebulae to F5.6 for 52 late-type spirals. The elliptical nebulae fall almost entirely within the narrow range G0 to G5, but the scatter increases conspicuously with progression along the sequence of classification.

A special investigation of the frequency of emission in extragalactic nebulae (in general, nuclear regions only) was based on 233 selected spectra in which $\lambda 3727$ would probably be detected if present. As Mayall found from fewer data, the frequency increases systematically through the sequence of classification, ranging from 20 per cent of the elliptical nebulae to 88 per cent of the late-type spirals. In elliptical nebulae, with stellar populations of type II, emission is restricted to the low excitation line, $\lambda 3727$. It is the only direct evidence available of the existence of interstellar material in these nebulae. The additional lines of higher excitation, which appear in spirals, are presumably excited by the blue supergiants found in stellar populations of type I.

SUPERNOVA IN NGC 3177

A supernova found by Hubble in NGC 3177 (Sb) on March 15, 1947, at $m_{pg} = 16.8$, was followed for three months until it reached $m_{pg} = 18.9$. The light-curve by Baade and a spectrum by Humason identified the star as a supernova of type II, discovered about a month after maxi-

mum. The radial velocity of the nebula, measured by Humason, confirmed the assignment to the well known group centered around NGC 3190, whose dis-

tance modulus is $m - M = 27.0$. Thus the supernova at maximum reached about $M_{pg} = -11$, with an uncertainty of about 0.5 mag.

LABORATORY INVESTIGATIONS

RELATIVE TRANSITION PROBABILITIES

The measurement of the relative gf -values (transition probabilities) of 471 lines in 100 multiplets of the spectrum of neutral vanadium ($V\text{ I}$) has been completed by R. B. King. The list includes the great majority of $V\text{ I}$ lines of astrophysical importance in the region $\lambda\lambda 3042-6812$, and is complete enough to permit a comparison of the laboratory and theoretical intensities of lines in multiplets and of multiplets in supermultiplets. About 55 per cent of the multiplets appear to exhibit normal line intensities, but the agreement between observation and theory for multiplets in supermultiplets is relatively poor.

The measurement of gf -values for lines of neutral nickel ($Ni\text{ I}$) in electric-furnace absorption spectra is virtually completed, but is limited to lines of excitation potential less than 0.5 volt. It will include most of the lines of astrophysical interest in the wave-length region $\lambda\lambda 3010-4400$.

Investigation of the intensities of bands in the Swan system of the carbon molecule C_2 is being continued. This has been undertaken primarily to obtain data to aid in interpretation of the well known behavior of these bands in the spectra of R- and N-type stars, where, in many cases, the bandheads belonging to molecules containing the carbon isotope C^{18} appear to be abnormally strong as compared with those due to molecules containing only the principal isotope C^{12} . Preliminary, semiquantitative comparisons by Sanford and King between laboratory and stellar band intensities in the Swan system in-

dicate that additional work to improve both sets of data is justified.

A photoelectric photometer is being developed in the laboratory by Mr. William W. Carter, of the California Institute of Technology, for the direct measurement of line intensities in electric-furnace emission spectra. If successful, the apparatus will be used first to extend the measurements of gf -values in the spectrum of $Fe\text{ I}$ to higher-level lines than were obtained by absorption-spectra measurements.

THE SPECTRUM OF DYSPROSIUM

The spectrum of the rare earth dysprosium, with its modifications depending on the laboratory light-source in which it is produced, is being studied by A. S. King. The examination includes wave-length measures of a large proportion of the lines, supplementing the lists at present available, also a classification of lines according to their intensities at different temperatures of the electric furnace, and the selection, by means of the spark spectrum, of lines arising from the singly ionized atom ($Dy\text{ II}$). The work thus far has covered the region $\lambda\lambda 4700-9300$, in which range about 2500 lines have been listed.

A notable feature of the dysprosium spectrum in this region is the large number of lines which are strong in the furnace at low temperature, many of these having only moderate intensity in the arc spectrum. The low-level lines of the $Dy\text{ I}$ spectrum are thus selected; and also those evidently from successively higher energy levels appear at higher furnace tempera-

tures and in the arc. In the latter sources, the more sensitive lines of $Dy\ II$ appear. These lines are found in the spectra of several stellar types.

FLUORESCENCE EXCITATION

A resurvey has been made by Bowen of coincidences between ultraviolet lines that might lead to the excitation of emission lines with abnormal intensities by a fluorescence mechanism. Three new coincidences that may be of astronomical significance were brought to light by this survey. One coincidence between Lyman β and an ultraviolet line of $O\ I$ appears to explain the abnormal intensity of the $\lambda 8446$ line of $O\ I$ in the emission spectra of several stars. Another coincidence between $\lambda 2795$ of $Mg\ II$ and a $Zr\ I$ line seems to provide an explanation for the abnormal intensity of a small group of $Zr\ I$ lines in the spectrum of χ Cygni, observed by Merrill.

INSTRUMENTATION

The design of the direct-intensity microphotometer has been completed by H. W. Babcock and Nichols. The calibration spectrograph for use with this microphotometer is finished, and the construction of the microphotometer is proceeding rapidly.

Babcock has constructed a photoelectric integrating exposure meter which is designed to aid in obtaining the correct exposure for spectroscopic photographs. In this instrument about 5 per cent of the

light passing through the slit is directed into an electron multiplier phototube; the resulting photoelectric current is integrated, and the sum is continuously indicated by a counting device. With an ordinary photomultiplier (931-A) and a rather crude circuit, the meter gave useful results on exposures with the coude spectrograph of A-type stars down to the fifth magnitude. If the best available tube (1P21) and a more refined circuit were employed, the instrument would probably be useful down to about the seventh magnitude.

An automatic guider for the 100-inch telescope has also been developed by Babcock. This guider introduces a new and simple type of optical scanning, whereby a rotating knife-edge modulates the starlight passing to a single photomultiplier and permits a phase-discriminating circuit to control the slow motions of the telescope in right ascension and declination in such a way as to keep the star on the optic axis of the guider and hence on the slit of the spectrograph. When properly adjusted, the guider keeps the star on the slit indefinitely with a precision fully equal to, if not better than, that of an observer doing manual guiding. The original guider, without any refinements, worked on stars to the sixth magnitude or fainter. The temporary addition of a preamplifier adds several magnitudes to its range. Theoretically, the limit of usefulness of a guider using an unrefrigerated 1P21 tube with the 100-inch telescope should be in the neighborhood of the thirteenth magnitude.

MAINTENANCE, OPERATION, AND NEW CONSTRUCTION

Early in 1946 the Observatory embarked on an extensive two-year program of repair and modernization of its physical plant. During the current year this program has progressed rapidly, and it should

be nearly completed by the end of the two-year period, except for a few items involving major shop construction. Because of the present labor shortage it has not been feasible to expand the personnel

of the shops to the point where they could handle the increased load of this reconstruction program in the scheduled period.

The following major items of this program have been completed during the current year:

1. Visitors' gallery for the 100-inch telescope.

2. Modernization of cottages and Monastery on Mount Wilson. This included the addition of a room and a deep-freeze unit at the Monastery. The efficiency and economy of operation of the Monastery has been greatly increased by these new facilities.

3. Photographic facilities on Mount Wilson. All darkrooms have been provided with refrigeration units, and a central cold-storage room has been installed for the storage of all unexposed plates on the mountain.

4. Rater for 100-inch telescope clock. This mechanical rater permits the rate of the clock to be changed by remote control from all observing positions without stopping the clock.

5. Stand-by power plant. This is a small gasoline electric plant which automatically

starts and takes over the load in case of failure of the power line from Pasadena. The great usefulness of this plant was emphasized after the breakdown of the power line during the storm of November 11-14, 1946.

6. Plate storage vault in Pasadena. In the 43 years of its operation, the Observatory has accumulated a collection of over 50,000 solar photographs, and over 50,000 spectrograms of 11,000 stars, as well as a large number of direct photographs of nebulae and other objects. In order to reduce as far as possible all hazards to this invaluable collection of plates, additional fire walls and an automatic fire-alarm system have been installed in the plate vaults. All equipment (such as comparators and measuring engines) that formerly involved the use of the vault for other purposes than plate storage has been removed in an effort to reduce still further the fire hazard.

All contracts in connection with national defense projects were completed by September 1, 1946, less than 4 per cent of the machine shop time for the year having been spent on these contracts.

THE LIBRARY

During the year 1946-1947, the library has accessioned 216 volumes, 87 from binding, 61 purchased, and 68 gifts, making a total of 15,998 volumes. Of the gifts, part have come from Dr. Hale's scientific library, a bequest described in previous annual reports, and a few from Dr. van Maanen's library. The yearly number of volumes bound is still small because of continued binding difficulties.

By the bequest of Dr. Adriaan van Maanen, who died in January 1946, his scientific library was left to the Mount Wilson Observatory. This valuable collection of about 500 volumes of bound periodicals and publications of observatories, and separate volumes, has now become the property of the Observatory; the work of marking them with a special bookplate and cataloguing them has begun.

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GEOPHYSICAL LABORATORY

Washington, District of Columbia

L. H. ADAMS, *Director*

It was reported a year ago that, after a review of past work and a redefining of aims, a newly integrated program for research at the Geophysical Laboratory had been outlined, and that the program placed primary emphasis on the study of the melting and solubility relations of silicates in the presence of water and other volatile components under pressure for the purpose of obtaining a more complete understanding of the genesis of rocks, other geologic phenomena, and the constitution of the earth as a whole. In the presentation of objectives and general methods of attack, it was recognized that necessary elements of the program would include

the measurement of thermal quantities, further investigations on selected anhydrous silicate systems, and certain field studies, and that active consideration should be given at the earliest practicable date to other means for accomplishing the main objectives of the program.

During the past year a fresh start has been made on the "wet silicate" problem, the "dry silicate" work has continued productively, preparation has been made for experimental work on thermal quantities, some investigations interrupted by the war have been rounded out, and the results of other previous researches have been put in form for publication.

EQUILIBRIUM RELATIONS IN HYDROUS MIXTURES

MAGNESIA—SILICA—WATER

A series of studies (Bowen, Tuttle) on the system $\text{MgO—SiO}_2\text{—H}_2\text{O}$ was carried out principally with the aid of the type of pressure vessel or bomb already in use at the Laboratory, an autoclave in which the magnesium silicate is heated together with a certain quantity of water. After being sealed, the vessel is heated to the desired temperature, and, depending upon the quantity of water added, a pressure of water vapor is developed which is known only approximately (because of our imperfect knowledge of the properties of water at high temperatures), but with sufficient accuracy to permit useful conclusions to be drawn. With this apparatus it is possible to determine the phases formed at the calculated pressure and at the measured temperature prevailing in the pressure vessel.

The method gives only preliminary orienting values, but in the system $\text{MgO—SiO}_2\text{—H}_2\text{O}$ it was ascertained quite definitely that no liquid phase is formed at temperatures and pressures attainable with this type of apparatus. Even with only solid phases and vapor present, it was found possible to prepare all the more common natural hydrous silicates of magnesium and also the anhydrous silicates forsterite and enstatite. Moreover, these phases appeared in a systematic manner suggesting that equilibrium was attained or closely approached; but in order to have full assurance of the attainment of equilibrium it may be necessary to add another oxide which will induce formation of liquid at the temperatures and pressures of the experiments. To this end it is proposed to add K_2O , but before proceeding farther it seemed desirable to investigate

the "dry" system $K_2O-MgO-SiO_2$, as reported in a later section.

The magnesium silicates formed in the experiments now completed are common in certain varieties of igneous and metamorphic rocks, and a knowledge of their ranges of stability with respect to pressure and temperature would throw light on the conditions of their formation in Nature. A few experiments on the same materials have been made with another type of apparatus, described below, which was designed to render possible the direct measurement of the pressure in the system and to facilitate all manipulations. With this apparatus it was possible also to go to a much higher temperature than with the conventional pressure vessel. Some of the results obtained in this manner are significant in connection with the supposed magmatic origin of certain serpentine masses. Thus, synthetic serpentine when heated to $900^\circ C$ at $15,000 \text{ lb/in}^2$ water pressure gave forsterite and enstatite. At $800^\circ C$ and $23,000 \text{ lb/in}^2$ pressure it gave the same products, and at $700^\circ C$ and $30,000 \text{ lb/in}^2$ it gave forsterite and talc, in all cases without formation of liquid. The last-mentioned pressure corresponds to an overburden of some four to five miles of impervious rock of density 2.7. No serpentine magma and no formation of serpentine in any manner can be regarded as possible under temperature-pressure conditions corresponding to those mentioned immediately above.

NEW TYPE OF PRESSURE APPARATUS

The apparatus with which these and other results to be described were obtained (Tuttle) consists of a small cylindrical pressure vessel made of stainless steel with an external diameter of $9/16$ inch, an internal diameter of $3/32$ inch, and a length of $7/8$ inch. The internal chamber

is only $3/8$ inch deep, so that one end is permanently closed. The other end is finished with a cone of much smaller maximum diameter than the cylinder, and when in use the pressure vessel stands with its closed end upward and its conical end resting in a conical depression in a stainless steel rod, which forms a cone-in-cone joint similar to that commonly used in pressure lines. In the stainless steel rod a minute axial bore is made which enters the bottom (apex) of the lower cone and permits access of water vapor to the charge in the small pressure vessel. A high-pressure pump supplies water at a pressure measured with a gauge. The pressure vessel is held in position and the cone joint is kept closed by means of another stainless steel rod, which rests on the upper, closed end of the pressure vessel and to which a downward pressure can be applied as a dead weight by means of a lever arm, in a manner similar to that used in a testing machine. In practice, a charge of 8 to 10 mg of the material to be investigated is placed in a minute platinum crucible, which is set on a silver pedestal that rests on the lower cone surface; the pressure vessel is placed in position over the charge; a weight is hung on the lever arm sufficient to balance the relatively small pressure developed over the very small area of the cone joint; a split furnace, like that commonly used in organic combustions but mounted in a vertical instead of the usual horizontal position, is swung into place around the pressure chamber and its accessory rods; and the chamber is heated to the desired temperature, which is measured by means of a thermocouple inserted in the wall of the pressure vessel. At the same time the water supply is pumped up to the desired pressure, and the water, which is necessarily converted to vapor at the temperature of the chamber, is admitted by opening a valve which re-

mains open throughout the run. When the run is completed the furnace is swung aside and a jet of air is directed against the pressure chamber. By this means the equilibrium is quenched, and after release of the pressure the charge can be removed for examination under the microscope and for determination of water content.

This apparatus has served to determine equilibrium up to 900°C at pressures up to $15,000\text{ lb/in}^2$ and at 800°C up to $30,000\text{ lb/in}^2$ in a variety of silicate mixtures in which equilibrium can be obtained in one hour. At lower temperatures and pressures it is possible to determine equilibrium in materials that require much longer runs. By substituting for the stainless steel a material having greater "hot strength" it will be possible to extend the range of experimentation.

STUDIES IN THE SYSTEM POTASH— ALUMINA—SILICA—WATER

The above-described apparatus has been used principally for determination of equilibrium of potassium aluminum silicates with water (Bowen, Tuttle). Glasses which had already been prepared by Schairer and Bowen for their investigation of the dry system $\text{K}_2\text{O}—\text{Al}_2\text{O}_3—\text{SiO}_2$ were used in the investigation. The liquidus temperatures for compositions lying on portions of two joins in this system have been determined for two isobars, $15,000\text{ lb/in}^2$ and $30,000\text{ lb/in}^2$. The two joins are the $\text{K}_2\text{O} \cdot 4\text{SiO}_2$ —leucite join and the $\text{K}_2\text{O} \cdot 6\text{SiO}_2$ —orthoclase join. The liquidus temperatures as determined for dry melts on the former join are lowered, in the orthoclase field, by a nearly uniform amount of about 100°C due to water vapor at a pressure of $15,000\text{ lb/in}^2$. The amount of water dissolved in the liquids at the liquidus temperatures increased from about

5 per cent in the high alumina compositions to about 20 per cent in the $\text{K}_2\text{O} \cdot 4\text{SiO}_2$ composition itself. At $30,000\text{ lb/in}^2$ pressure of water vapor there is further lowering of the orthoclase liquidus curve amounting to about 40°C , and the content of water in the silicate liquids at liquidus temperatures is nearly doubled for the more aluminous mixtures, but is increased only about 25 per cent as the $\text{K}_2\text{O} \cdot 4\text{SiO}_2$ composition is approached.

The other join ($\text{K}_2\text{O} \cdot 6\text{SiO}_2$ —orthoclase) gives comparable results at $15,000\text{ lb/in}^2$, but at $30,000\text{ lb/in}^2$ there is scarcely any additional lowering even though the amount of water dissolved in the liquids is significantly greater at the higher pressure. Evidently, the tendency of increased pressure *per se* to raise the melting temperatures acts counter to the effect of pressure in inducing a greater solubility of water and consequent lowering of melting temperatures. It is possible, therefore, that these mixtures may exhibit a minimum melting temperature on their p-t curves, a question that will be investigated further. Such a minimum melting temperature is of particular interest in connection with magma formation, and in the earth might give rise to an asthenosphere (a zone of easy melting) with rigid zones both above it and below it, a situation that would account for some seemingly contradictory geophysical phenomena, such as isostatic adjustment, general earth rigidity, and deep-focus earthquakes.

GRANITE—WATER

The new apparatus affords a simpler means of studying the equilibrium of granite with water, and some experiments are being made in continuation of Goranson's previous studies of these compositions (Bowen, Tuttle).

STEAM-QUENCHING FURNACE

The improvement of this apparatus preparatory to the carrying out of a number of studies that have been planned has proved a somewhat troublesome matter, but work has been progressing satisfactorily (Morey, Ingerson). A new pressure vessel has been designed with a view to eliminating some of the previous difficulties. Another type of apparatus consists of a pump, similar to that used by Bowen and Tuttle, connected to one of the conventional pressure vessels by a screw closure and suspended in an electric furnace, the pressure being led into the apparatus through a capillary hole in the plunger. This hole is threaded inside the vessel and a capillary carries the water down to the bottom. This was found to be necessary to prevent chilling of the copper washer at the seal, with resulting leakage. A collar is threaded on the upper part of this capillary, from which four quenching charges can be suspended. Many runs have been made with this apparatus, and it has worked well.

By proper control of the cooling rate it is possible to cool the charges without their "puffing up," an annoying and mysterious behavior of specimens in the quenching furnace. Several water determinations have been made on homogeneous melts so obtained. It is difficult to summarize the results in tabular or graphic form, but it has been established that the compositions at and near the eutectic between sodium disilicate and quartz show a continuous solubility past the critical temperature of water; that is, the solubility curve

in this region does not intersect the critical region. This leads to great complication in the phase equilibrium diagram of this system. The solubility curves of both sodium metasilicate and sodium disilicate are retrograde below the critical temperature of water, and each curve shows a lower critical end point at a temperature which is practically that for pure water. Previous work has shown that with sodium disilicate this end point lies not much above 380°C and is at a pressure of the order of 750 atmospheres. Moreover, the intersection of the critical curve and solubility curve takes place while the pressure along the three-phase curve is still increasing with decreasing temperature. Since there is no intersection along the boundary curve, it will show a maximum along its p - t curve. Hence, some region of higher Na_2O content will show the transition between these two types. The work on this system should be completed next year.

FILTER AUTOCLAVE

Work is being resumed with the apparatus developed before the war for the purpose of filtering high-temperature solutions *in situ* (Burlew). The apparatus was successfully used for measurements on alkali-carbonate-water solutions. A paper embodying the results of that investigation (Burlew, Morey) will be completed at an early date. Further work with the autoclave will be for the immediate purpose of determining more thoroughly its general utility for equilibrium studies in mixtures of silicates with water under pressure.

EQUILIBRIUM RELATIONS IN ANHYDROUS MIXTURES

NEPHELINE—"POTASH NEPHELINE"—SILICA

Substantial progress was made on the determination of the three-phase boundaries necessary to define the composition of

the nepheline solid solution in equilibrium with liquids, leucite, and alkali-feldspars in "petrogeny's residua system" (Schairer). Suitable compositions in the very viscous

region near the feldspar-silica boundary curve were prepared and put in furnaces to crystallize for several months or even years, in order to ascertain whether crystallization is possible, or whether because of failure of the melts to crystallize it is impracticable experimentally to determine the phase relations in this particular region.

ALBITE—ANORTHITE—SILICA

Upon examination of the data previously obtained it was found that all results were not consistent, and that for the precise location of some of the three-phase boundaries (those at the lower temperatures) longer runs than had been given were required. These longer runs were made during the year, and the data are now essentially complete (Schairer).

POTASH—MAGNESIA—SILICA

In order to approach the problem of the stability and crystallization relations of biotite in igneous rocks, a knowledge of the dry quaternary system $K_2O-MgO-Al_2O_3-SiO_2$ is necessary before H_2O can be included as an additional component (Schairer).

The ternary system $K_2O-MgO-SiO_2$ is one of the limiting systems of this quaternary system. Since no information on the phase relations in the ternary system was available, plans were made to begin an investigation of it. Mr. Edwin W. Roedder, of Columbia University who has been granted a one-year fellowship by the Carnegie Institution, will work with Schairer on this ternary system, beginning in September.

In order that the work might be started promptly, nine compositions were prepared to explore the general relations, and quenching runs were completed on these nine compositions. This preliminary re-

connaissance showed that the fields of forsterite and periclase occupy a large portion of the liquidus surface in this system. The only compositions that do not lie in either the field of forsterite or that of periclase are in that portion of the system with less than about 15 per cent MgO or with about 70 per cent or more SiO_2 . Two ternary compounds, one isometric and the other hexagonal, but as yet unidentified as to composition, were encountered in the preliminary reconnaissance.

POTASH—MAGNESIA—ALUMINA—SILICA

Work on this quaternary system (Schairer) has been outlined, and K_2O-SiO_2 glasses have been prepared for use as a source of K_2O in making the quaternary compositions. Two planes which might be ternary systems within the quaternary system were selected for study. These are forsterite-leucite-silica and potassium disilicate-forsterite-leucite. Reconnaissance compositions have been selected, and six melts in the join forsterite-leucite-silica are now in preparation.

PREPARATION OF MANUSCRIPTS FOR PUBLICATION

A summary paper giving the final diagrams for $Na_2O-Al_2O_3-SiO_2$ and $K_2O-Al_2O_3-SiO_2$ and the principal results (but not the detailed data) was prepared and published (Schairer, Bowen) under the title "Melting relations in the systems $Na_2O-Al_2O_3-SiO_2$ and $K_2O-Al_2O_3-SiO_2$."

Another paper already prepared embodied the experimental results for the system anorthite-leucite-silica and some of the applications to petrology (Schairer, Bowen). A broad discussion of the origin of leucite-bearing and other alkaline rocks was not included in this paper and is reserved for a future paper to be written

when the system KAlSi_3O_8 — $\text{NaAlSi}_3\text{O}_8$ — SiO_2 is completed.

Numerous diagrams have been prepared for the systems Na_2O — Al_2O_3 — SiO_2 and K_2O — Al_2O_3 — SiO_2 (Schairer), and the tables of experimental data are now complete. The manuscripts of the detailed papers will be completed at an early date. Diagrams were made just before the war for a paper entitled "The quaternary system CaO — FeO — MgO — SiO_2 . I. Some relations in the join CaSiO_3 —akermanite— FeO " (Schairer, Osborn). The data are about to be assembled for publication. Another paper will present the results of studies on the melting relations in the system FeO — Al_2O_3 — SiO_2 (Schairer), the measurements on which were completed in 1940.

Work on the system diopside—anorthite—silica (Greig) was undertaken some years ago with the expectation that, except for the region where two liquids coexist, the system would be a simple ternary one with a eutectic, and that it would, therefore, involve but little work. The liquidus surfaces were readily located, but a slight difficulty was encountered, arising from the circumstance that, although tridymite is the stable form of silica at the eutectic temperature, cristobalite rather than tridymite is always formed. There is reason to believe that the tridymite liquidus surface lies only slightly above the cristobalite liquidus surface, and it is, therefore, to be expected that the stable eutectic will be close to the measured metastable eutectic that has cristobalite as the silica phase. A complication was found in the "binary" system diopside—anorthite. Contrary to expectation, this system proved not to be a simple binary one. The results of the investigation are to be prepared for publication without further experimental work on it, and in particular without an

attempt to determine the true eutectic with tridymite.

Some time ago, a number of experiments were made on the melting of natural rocks (Greig, Shepherd, Merwin). This work began in an effort to determine the relative melting temperatures of granite and basalt (diabase). After the determination of the temperatures of complete melting and the temperature range of melting, the measurement of the liquidus temperature was extended to cover a series of rocks ranging in composition from a typical basalt to siliceous obsidian. An effort was made to find a practical method for more detailed phase equilibrium work on basaltic rocks. Unfortunately, the melts reacted with all the containers that were tried, so that their composition did not remain constant. It is now planned to write up for publication the results of this investigation with a minimum of additional experimental work.

A comprehensive revision of the first three-component system worked out at the Geophysical Laboratory, namely, the system CaO — Al_2O_3 — SiO_2 , has been undertaken by Wright. The results of this work are important not only in petrology, but also in the cement industry, the research organizations of which have encouraged the bringing up to date and republication of this basic information.

The original work on the iron-copper sulfides contained only abbreviated descriptions of the products. Subsequently, further studies of the textures of the products were made, and a series of natural-color photographs were taken (Merwin, Greig). Plans are being made to assemble these results properly and publish them together with some of the color photographs.

The old work on the system Na_2O — CaO — SiO_2 has been assembled and studied

(Morey). The material ready for publication includes a large number of mixtures—more than in the original publication—made primarily for the density-index study published with Merwin. A phosphate system which is part of the ternary system $\text{Na}_2\text{O}—\text{K}_2\text{O}—\text{P}_2\text{O}_5$ included within the limits $\text{NaPO}_3—\text{Na}_4\text{P}_2\text{O}_7—\text{K}_4\text{P}_2\text{O}_7—\text{KPO}_3$ still requires some additional measurements (Morey).

Other past investigations, the results of which are about ready for publication, include the phase relations in the systems tellurium—silver—gold and potassium disilicate—sodium disilicate, and studies of transitions in compounds of silver with sulfur and other elements (Kracek).

As fast as the various subjects included

in the investigations carried out in connection with the war work have been declassified, steps have been taken to assemble the results that are of more than ephemeral value and put the information in form for publication. Some of this work has produced results of direct or indirect applicability to the current program of the Laboratory, as, for example, the work on artificial willemite needles (Ingerson, Tuttle, Geophysical Laboratory publication no. 1090). Among papers scheduled for early publication are those on the double fluorides of zinc (Ingerson, Morey); the systems $\text{K}_2\text{O}—\text{ZnO}—\text{SiO}_2$, $\text{ZnO}—\text{B}_2\text{O}_3—\text{SiO}_2$, and $\text{Zn}_2\text{SiO}_4—\text{Zn}_2\text{GeO}_4$ (Ingerson, Morey, Tuttle); and the decomposition of analcite (Ingerson, Morey).

THERMAL QUANTITIES

As was emphasized in the outline of the Laboratory's program for future research, presented in the annual report last year, effective application of the results of laboratory measurements of silicate equilibria requires reliable data on specific heats, latent heats of fusion, heats of solution, and heats of reaction of rock-forming substances. The existing information on this subject is wholly inadequate, and it is, therefore, very important that active attention be given to thermal measurements. As a first step in setting up a calorimetric program, a careful survey of existing data on rock-forming minerals was carried out (Kracek). The report embodying the results and conclusions points the way toward the most profitable lines of experimentation.

For the immediate future we plan to carry out measurements of the heats of solution, in appropriate solvents, of a number of the more important types of silicate minerals, in both the crystalline and the glassy condition. From the differences in

the values for the crystals and corresponding glasses, combined with data on specific heats, the latent heats of melting at the melting point will be deduced. It may be noted in passing that by a well known thermodynamic relation the latent heat of a mineral is related to the slopes of melting curves in equilibrium diagrams of which the minerals are constituents.

Values of specific heats in some cases are already available, partly from the early work of this Laboratory and partly from work performed elsewhere. For a well rounded program of thermal studies, it is important that further studies of specific heats be made in the near future.

Apparatus for measuring heats of solution is under construction. It consists of a 900-cm³ gold calorimeter solution vessel (in which the mineral can be dissolved in hydrofluoric or other acids, or in alkali solutions) and the associated calorimetric equipment necessary for measuring the heat evolved during the solution process. Apparatus for the measurement of specific

heats at high temperatures will be added during the coming year. Calorimetric studies, for our purposes, may be divided into three categories: (a) collection of data for a specific purpose, that is, directed toward a particular petrologic problem; (b) application of an indirect, thermodynamic, method for obtaining heats of transformation; and (c) research in calorimetry, directed toward improvement of existing methods and development of new methods. In the program as planned, the emphasis initially is placed on the collection of data through the medium of methods already developed. The data thus obtained should be fitted to a thermodynamic framework in a more detailed manner than has been the custom heretofore. The substances awaiting study are so numerous that it seems wise to select for immediate study those that are the more important petrologically. Accordingly, we shall begin with measurements on wollastonite, diopside, and enstatite, to be followed by orthoclase, albite, anorthite, leucite, nepheline, "potash nepheline," and various other silicates and aluminosilicates that form the more abundant constituents of rocks.

The essence of the indirect method for determining the stability relations of minerals is to measure the specific heats of the appropriate compounds over a range of temperatures, including very low temperatures, to determine also a heat of reaction at a convenient temperature, and then to utilize a simple principle of thermodynamics so as to calculate the temperature at which the reversible transformation in question takes place at one atmosphere pressure, or the pressure at which the transformation takes place at a specified temperature. It is expected that this procedure will broaden our knowledge of thermal relations in petrology by allowing us to determine the conditions under which a mineral may be formed from

another mineral or combination of minerals even when it is impossible by existing experimental techniques to observe the transformation directly.

A splendid start has been made on the thermal part of our program through the efforts of Dr. Th. G. Sahama, who received an appointment as research associate of the Carnegie Institution and who has been generously accorded the privilege of working initially at the Pacific Experiment Station of the United States Bureau of Mines, at Berkeley, California. Using the hydrofluoric acid solution calorimeter developed by Dr. K. K. Kelley and his associates, Dr. Sahama has been attacking the general problem of the stability of the orthorhombic pyroxenes. As is well known, the magnesium compound MgSiO_3 (enstatite) is a stable form, and of widespread natural occurrence. The corresponding iron compound FeSiO_3 (orthoferrosilite) has not been found in Nature and has not been prepared artificially. However, isomorphous mixtures of FeSiO_3 and MgSiO_3 up to about 80 to 90 per cent FeSiO_3 are known. Accordingly, it has been concluded that the pure FeSiO_3 is unstable.

By determining the free energy change in the reaction $(\text{Mg,Fe})_2\text{SiO}_4 + \text{SiO}_2 = 2(\text{Mg,Fe})\text{SiO}_3$ with changing Mg-Fe ratio, it should be possible to find out whether or not pure FeSiO_3 is thermodynamically stable, and, if it is unstable, where the stability limit in the series $\text{MgSiO}_3\text{--FeSiO}_3$ lies. The solution of this problem in this way, if it should prove possible, would illustrate the importance, as well as the possibilities, of the application of thermochemical and thermodynamic methods for investigating the formation of minerals in natural rocks. This investigation may shed light on the observation that ferrous iron-magnesium silicate, if extremely rich in iron, crystallizes in the form of the orthosilicate (fayalite) together with

quartz, and, if containing less iron, reacts with silica and forms metasilicate (pyroxene).

To solve this particular problem, measurements of heats of formation and specific heats of the several compounds are necessary. Fortunately, specific heats at low temperatures were previously measured at the Pacific Experiment Station. The heats of formation of a number of natural olivines and pyroxenes, as well as of artificially made Mg_2SiO_4 , $MgSiO_3$, and Fe_2SiO_4 prepared at the Station, have now been measured with the solution calorimeter.

This calorimeter, as used for the determination of the heats of solution of minerals in hydrofluoric acid solutions, is constructed in such a way as to allow measurements at temperatures somewhat above room temperature, for instance, at $+75^\circ C$. The solution vessel is made of platinum so that hydrofluoric acid can be used as solvent. Accordingly, with this calorimeter all silicate or other minerals which

are sufficiently soluble in the hot HF solution can be determined. More specifically, the heats can be measured for those silicate minerals of which about 1 gm of material completely dissolves in about 800 ml of hydrofluoric acid during a time of at most 30 minutes and at a temperature of no more than $+75^\circ C$. It would be possible, therefore, to make calorimetric determinations on most substances on which a ferrous iron determination can readily be carried out by ordinary analytical methods. Of course, besides pure hydrofluoric acid, all other acids or acid mixtures not attacking platinum can be used as well.

Although, for the time being, primary emphasis is to be placed upon the measurement of thermal quantities by such techniques as are available for immediate use, attention to the development of new methods will be given as the thermal work progresses, with the expectation that more exact and effective procedures will be found.

VOLCANIC PRODUCTS

A variety of interesting rocks, incrustations, and miscellaneous products are being subjected to systematic chemical and microscopic studies (Zies, Merwin) for the purpose of obtaining a better understanding of various aspects of volcanic activity.

Several weeks were spent in reviewing the samples that were collected at Santiaguito (the new volcanic edifice located on the old volcano of Santa Maria in Guatemala), the samples from San Miguel in El Salvador, and the samples from Batoer on the island of Bali in the Dutch East Indies. It has seemed preferable for the immediate future to confine the work to the study of samples collected on the various expeditions to Santiaguito. This work includes the study of (1) the fresh

rocks, (2) the rocks altered by fumarolic activity, and (3) the condensates of the fumarolic emanations. These emanations, issuing at a temperature of $350^\circ C$, consist mostly of steam, but preliminary examination begun before the war revealed the presence of an unusually large content of hydrochloric acid, sulfuric acid, and sulfur dioxide. Hydriodic, hydrobromic, hydrofluoric, and boric acids were present in much smaller amounts. In view of the fact that these are commonly referred to as minor constituents, the quantities are surprisingly large. The approximate amounts of the acid constituents in one liter of the aqueous condensate are as follows: HCl and H_2SO_4 , about 8.0 gm each; SO_2 , about 0.4 gm; HI, 5 mg; HBr, 20 mg; HF, 65

mg; and B_2O_3 , 55 mg. Even a casual glance at this list of constituents will impress one with the desirability of enlarging our empirical background, by obtaining additional evidence from combined field and laboratory studies that will broaden our knowledge of the role of volatile constituents in the formation of rocks.

Some time was spent in trying out various known methods for the positive identification of the hydrobromic acid, and a further effort was made to adapt the chosen method for its estimation in the highly acid condensates. This work is now well enough in hand so that the method can be applied to all samples collected. An attempt will also be made to find the various volatile constituents in the fresh rock. This may not prove feasible with respect to the minor constituents, but

it is believed that the effort should be made in order to show whether the rock extruded by Santiaguito is the actual source of the volatile constituents.

In the course of these studies, it has been found that the fresh rock is of more than casual interest. The word "fresh" here must be used advisedly, for it appears that the rocks have undergone significant changes during the slow period of their extrusion. It is not improbable that the relatively low temperatures at which the rocks reached the surface can be correlated with the changes in mineral composition and with the volatile constituents. In this connection, it should be noted that in 1940 the temperature of the extrusion of such rocks was measured and found to be approximately 725° C.

STUDIES ON RADIOACTIVITY

Several researches involving the distribution of radioactivity in materials of the earth's crust were interrupted by the war. Most of these were of sufficient importance to justify rounding out the investigations and putting the results in form for publication. During the past year, the work on the radium content of ultramafic rocks (e.g., peridotites and dunites) has been completed, and one manuscript has been prepared (Davis). This project was undertaken in co-operation with Dr. H. H. Hess, of Princeton University, for the purpose of shedding light on the connection between mountain building and the intrusion of masses of serpentine or peridotite. A second manuscript dealing with the interpretation of the results will be ready soon.

Another project interrupted by the war had to do with the radium content of some varved clays obtained through Dr. E. A. Johnson, of the Department of Ter-

restrial Magnetism of the Carnegie Institution. These clays exhibited some very interesting radioactive properties. There is a definite rhythm in the radium content, the summer portions of the varves having only about 60 per cent of the radium content of the winter portions (Urry). Moreover, the radium content of the summer portions of the varves increases with time, whereas that of the winter portions decreases. A time scale has been established by Antevs, but it has as yet proved impossible to tie this scale in satisfactorily with the historical time scale.

One of the objects of investigating the varved clays was to explore the possibility that relations between the radioelements were similar to those that had previously been found in ocean sediments. In this case the curves of radium content against time would represent portions of one or another of the curves that were given for the radioelements in nonequilibrium systems. Anal-

ysis of the data obtained for the varved clays indicates that this is possible, and, therefore, it may be feasible to extend Antevs' scale to the present.

Messrs. O. W. Torresson and T. J. Murphy, of the Department of Terrestrial Magnetism, kindly collected for us this spring (1947) for determination of the water content some fresh sealed samples of the same varves from which samples were obtained in 1940 by Messrs. Piggot and Johnson. These determinations, which have been completed, are of interest in other fields as well as our own. The radium content of the water portion of the clays was also measured this year.

Independent analyses of the summer and winter curves of radium content against years (Antevs) yield the same age for the varved clays of Hartford, Connecticut, namely, 18,000 years. Although the attack is to be regarded merely as a preliminary one, the measurements as planned by us have been completed, and the results are being written up.

RADIUM AND URANIUM CONTENT OF SEA WATER

An investigation of radioactivity relations in sea water was commenced just before the war in collaboration with Dr. Elizabeth Rona, now of Trinity College, and with the assistance of the Woods Hole Oceanographic Institution. The measurements of the radium content of sea water and also of a few samples of river water—which proved to be of theoretical interest in connection with the work on sea water—were completed in 1942.

Of particular interest is the ratio of radium to uranium, which we find is much higher in river water and much lower in sea water than the ratio pertaining to radioactive equilibrium. The results, which are now being assembled

for publication, may have long-range economic importance because they appear to explain the very different uranium contents of fresh-water and marine black shales.

Some determinations of the radium content of meteorites have been made (Davis, Urry) because of the bearing of such results on the radioactivity of ultramafic rocks, mentioned above. The radium content of the iron meteorites and of the olivine-iron meteorites is not well established by existing results, which show wide discrepancies. It seemed desirable, therefore, to make a few determinations (Davis, Urry) on specimens of iron meteorites and pallasites kindly contributed by the United States National Museum. Results obtained by two different methods show puzzling differences and indicate that further research on the methods of determining radium in the metallic parts of meteorites is needed.

As a result of a conversation between Dr. Victor F. Hess, of Fordham University, and Dr. Merle A. Tuve, Director of the Department of Terrestrial Magnetism, regarding the observations by Hess that the ionization produced by the heat radiation from rocks is not accounted for by the measured uranium, thorium, and potassium content of the rock, Dr. Tuve proposed that a sample of rock with a negligible radioactive content be sought in order to test the idea that extraneous ionization might be produced by a cosmic-ray transition in the mass of rock surrounding the ionization chamber. The Balsam Gap dunite seems to be the most suitable for such an experiment, and we undertook to obtain an adequate sample for use by Dr. Hess.

As a further test of the hypothesis, an experiment is being made (Urry) whereby the ionization produced by granite from Quincy, Massachusetts, is measured, first,

in the natural state, and, second, after the addition of amounts of uranium, thorium, and potassium which are equivalent to the amounts of these contained in the granite.

Because of the interest attaching to the dunite deposits near Balsam Gap, North Carolina, two trips were made to this locality. The first, by Davis and Urry,

was for the purpose of obtaining material for mineral separation; and the second, by Davis and Urry with Murphy of the Department of Terrestrial Magnetism, was for the purpose of collecting about one thousand pounds of the dunite to be used in the co-operative research, mentioned above, on some apparent anomalies in the radioactivity of rocks.

OTHER INVESTIGATIONS

In addition to the systematic study of volcanic products mentioned above, Dr. Merwin, as research associate, has been preparing a series of diagrams representing the densities, the refractive indices, and the refractive dispersions of organic liquids that are of interest in connection with the determination of refractive index of mineral grains by the immersion method.

A start has been made on a project for the orderly application of statistical methods to some fundamental problems in geology. There are those who believe that progress in the broad field of rock formation is handicapped by the lack of clear correlation of laboratory experimentation with field observations, and that in many instances far-reaching conclusions have been drawn by incomplete or haphazard utilization of existing data. As an example of this, it has been stated that in the Bancroft region of Ontario, Canada, granite has been transformed into syenite and then into foyaitite, and it is important for

the understanding of the genesis of such rocks to know whether there is actually such a transition or not. Dr. Felix Chayes has been given an appointment as research associate of the Institution for the purpose of conducting studies on the application of certain statistical methods to petrometry. Beginning in May 1947, he started field work in New England areas and has been collecting a series of specimens for examination. As the report year closes, he is about to come to the Geophysical Laboratory to continue the investigation.

The co-operative work with the Department of Terrestrial Magnetism on deep seismic prospecting of the earth's outer layers is progressing satisfactorily. Information concerning the status of the project will be found in the report from that Department.

During the year the following papers were completed and submitted to technical journals for publication.

SUMMARY OF PUBLISHED WORK

(1088) Magmas. Norman L. Bowen. *Bull. Geol. Soc. Amer.*, vol. 58, pp. 263-280 (1947).

Address of the retiring president of the Geological Society of America given at the annual meeting of the Society at Chicago, December 26, 1946.

The address is concerned with some of the much-discussed problems of petrogeny, including the nature and origin of primary

magmas and the manner in which derivative magmas are formed.

High-temperature studies of silicates in the laboratory tend to support the opinion, based on field evidence, that basaltic magma is a primary magma and that most other magmas are derived from it. There is now a general tendency to adhere to this opinion as regards the magmas that are associated with surface

volcanism and the formation of hypabyssal masses. The question whether the great deep-seated masses of granite and closely related rocks can be regarded as derived from basaltic magma is much debated. Many investigators find no difficulty in accepting a large-scale differentiation in plutonic masses similar to that shown in some hypabyssal masses. On the other hand, many turn to altogether different processes for the production of most granite. These range from the supposed refusion of the granitic shell of the earth, which leaves the problem of the formation of this shell unsolved, to formation by metasomatic replacement of pre-existing rocks by means of hydrothermal solutions, and even to ion wandering in the crystal lattices. There is little prospect of early agreement on these questions.

A fundamental if not a wholly dominating position for basaltic magma being granted, it is important to know the exact nature of this primary material. Whether primary basalt has a notable water content or is nearly "dry" is a question on which divergent views are held. A decision is not readily reached on account of the possibility of contamination by extraneous water, but a comparison of the mineralogy and grain of deep-seated and surface manifestations seems to support the view that the water content is quite small and that it is only in derivative magmas that water may rise to notable proportions.

Peridotite is regarded as a primary magma by some investigators, and the existence of such magmas with a water content high enough for direct formation of serpentine has been suggested. The balance of evidence seems to favor the cumulative rather than the orthomagmatic origin of peridotite and the secondary nature of serpentine, but many difficulties remain in connection with serpentine "intrusives."

(1089) Melting relations in the systems $\text{Na}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ and $\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$. J. F. Schairer and N. L. Bowen. *Amer. Jour. Sci.*, vol. 245, pp. 193-204 (1947).

The phase equilibrium relations in the ternary systems $\text{Na}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ and $\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ are presented in this preliminary paper by means of four diagrams.

Temperature and composition data are given for eleven ternary invariant points and nine binary invariant points in the system $\text{Na}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ and for eleven ternary invariant points and ten binary invariant points in the system $\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$. The outstanding features of the two ternary systems are briefly presented. The very numerous data on which the diagrams are based and a full discussion of the preparation of the compositions studied, quenching data, the results, and some of the applications will appear later.

(1090) Artificial willemite needles. Earl Ingerson and O. F. Tuttle. *Amer. Jour. Sci.*, vol. 245, pp. 313-319 (1947).

Clear fluorescent needles of willemite have been grown in heated bombs from SiO_2 and $\text{Zn}(\text{OH})_2 \cdot x\text{Mn}(\text{OH})_2$, with ratios of length to diameter up to 1200:1 and with lengths up to 3 cm. The length and length:width ratio increased as pressure was brought below the critical pressure in an 18-cc bomb; also, as the temperature was raised. Optimum pressure was about 1000 lb/in² for an 18-cc bomb and about 4000 lb/in² for one with a volume of 280 cc.

Fluorescence increased with increasing $\text{Mn}(\text{OH})_2$ up to about $\text{Zn}(\text{OH})_2 \cdot 0.2\text{Mn}(\text{OH})_2$. With higher concentrations, tephroite (Mn_2SiO_4) crystallized along with the willemite. $\text{Mn}(\text{OH})_2$ in excess of 0.006 appeared to modify the habit of the willemite, making the crystals shorter and thicker.

Runs in an unlined steel bomb sometimes produced well formed crystals of fayalite in the crucible containing silica. In one such run the temperature was 439° C; pressure, 240 atmospheres.

The results indicate that if proper cognizance is taken of geologic occurrence and other factors, crystal habit might give some indication of relative temperatures and pressures of formation, especially in sublimates and in vesicles in extrusive rocks.

(1091) Liquid inclusions in geologic thermometry. Earl Ingerson. *Amer. Mineralogist*, vol. 32, pp. 375-388 (1947).

A satisfactory method of determining temperatures of crystallization of minerals from

the contained liquid inclusions would aid in the solution of many problems of geologic thermometry. The method has been in use for nearly ninety years, but recently published data on the specific volume of water at high temperatures and pressures allow much more accurate determination of the effect of original pressure than has been possible before. These data are here applied to the liquid inclusion problem for the first time. Data on the critical temperature of aqueous solutions of alkali halides provide the basis for better evaluation of the effect of concentration.

The fundamental assumption is that a liquid inclusion cavity was completely filled with fluid at the temperature and pressure under which it was formed. It must also be established that the inclusions are primary and that no leakage has occurred. Other necessary assumptions are that the change in volume of the mineral itself is insignificant and that changes in volume and concentration brought about by deposition of material from the solution as it cools are such as not to affect the results.

Curves have been prepared showing the relation between degree of filling of inclusions and temperature of disappearance of the vapor phase, both for pure water and for a 10 per cent solution of NaCl and KCl. Two sets of curves show the relation between temperature of disappearance of the vapor phase, pressure at the time of formation, and temperature of formation.

Observational difficulties are discussed, and one is illustrated by means of photomicrographs. Uncertainties of interpretation are also discussed, including those involved in estimating original pressure.

Measurements on quartz from pegmatites indicate temperatures below 250° C, including pressure corrections of 54° to 73° C for specimens whose depth at time of formation can be estimated. As most other vein minerals and many of those in igneous and metamorphic rocks contain liquid inclusions, it is

possible that this method may aid in the revision of considerable parts of the scale of geologic thermometry.

- (1092) Testing gun steel and other alloys and metals for resistance to surface cracking. Earl Ingerson. Amer. Inst. Min. and Met. Engrs., Metals Technol., vol. 14, Tech. Pub. No. 2223, 13 pp. (1947).

During the war, studies on gun erosion were conducted at the Geophysical Laboratory. The so-called heat checks in guns appear to aid erosion. For this reason it was desirable to develop a method for testing the resistance of metals and alloys to surface cracking under conditions of temperature, pressure, and action of powder gases similar to those obtaining in guns.

The test consisted in placing rod-shaped specimens with flat sides in a modified erosion plug and allowing part of the hot explosion gases to flow past the surfaces during a series of shots. The flat sides facilitated examination and photography. The results of tests on various materials are summarized in tabular form, and remarks are made in the text about most of the materials.

Three kinds of cracks are described: (1) "heat checking," (2) "coarse cracking," and (3) "post-fusion cracks." Their development and relations to grain boundaries are discussed, and illustrated with photomicrographs. Heat checking may be due to rapid heating and cooling of the surface; possibly surface changes produced by the hot gases play a part. The coarse cracking is tentatively ascribed to mechanical shock. Post-fusion cracks are produced where there is actual melting of the surface.

In these tests, the erosion per round increases with increasing number of rounds. Erosion of the rods is caused by continued development of cracks and undercutting, with eventual tearing out of fragments, rather than by melting and "wiping off" of metal from the surface.

- (1093) Annual report for 1946-1947.

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TUTTLE, O. F. See INGERSON, EARL.



DERWOOD EXPERIMENTAL LABORATORY

This Laboratory replaces the Kensington field station and provides the base for experiments in the high atmosphere, ionosphere, and related physical and solar phenomena including experiments involving radio echo sounding, cosmic rays, solar noise, atmospheric ozone, and many related effects. The building in the upper right at the circle is the main experimental building across the road to the left are the Quonset huts for storage and auxiliary power and immediately adjacent are the searchlight building and the cosmic ray building. In the lower right building, rapid run ionospheric recordings are conducted. At the lower left are the laboratory and associated radar for recording of solar noise, radio field intensity, and the like.

DEPARTMENT OF TERRESTRIAL MAGNETISM

Washington, District of Columbia

MERLE A. TUVE, *Director*

REVIEW OF MAGNETIC SURVEY AND OBSERVATORY PROGRAM OF THE DEPARTMENT OF TERRESTRIAL MAGNETISM, 1904-1946

Introduction. As older programs initiated by this Department approach maturity, it is appropriate to outline their history, the main ideas inspiring their creation, principal results achieved, and tasks left undone, with a forward-looking account of the future potentialities of these programs. Publication of results of the magnetic and electric survey of the earth and of results of observations at observatories is nearing completion, and the time seems now ripe to review these large-scale past operations of the Department, with interest in the high hopes which engendered the programs, and with the perspective afforded by the passing of the years. In much the same way we hope to review in future years the multifrequency ionosphere-recording and nuclear physics programs of the Department, from which emphasis likewise is being shifted, with effort in fresh directions.

It is to be noted that these programs in which the Department can claim with some truth to have pioneered on a major scale are in no sense terminated. On the contrary, they have expanded, usually far beyond the scope of the most active phase of our participation, in the hands of others. This statement is not true as concerns the magnetic survey of the oceans, which terminated with the sinking of the *Carnegie* in 1929, but the volume of new ocean magnetic measurements by airplane, after suitable instruments are developed, will no doubt in some years much surpass that acquired previously.

Much of the work here described was made possible by the whole-hearted co-operation of many individuals and organizations.

The early program of the Department. The Department's program of magnetic survey and observatory work, now being terminated, was set forth in general terms as two of three problems for attack in the initial proposal of 1903 for the founding of a Department of International Research in Terrestrial Magnetism by the Carnegie Institution of Washington. The third problem suggested was that of magnetic observations in ocean depths and atmospheric regions, and experiments of limited duration along these lines, instead of wide surveys, are included in our present program. However, though the major purpose stated was to investigate such problems of world-wide interest as relate to the magnetic and electric condition of the earth and its atmosphere, there can be little doubt that in the background there was hope of discovering the origin of the earth's magnetic and electric fields.

It is relatively easy to understand why the proposal for a world magnetic and electric survey would appeal to the imagination of the Trustees and President of the Institution in 1904. The earth's fields had been explored in only a few areas. The oceans, covering three-quarters of the area of the globe, as well as the polar regions, were largely open gaps. In vast areas such as the northern Pacific Ocean magnetic observations had never been

made. Here, then, was something to be done toward advancing scientific progress which should be of lasting benefit to mankind.

It seems likely also that Dr. Bauer, the moving spirit in the founding of the Department, hoped much from the more accurate mathematical representation of the geomagnetic field which would be made possible by a survey with wide coverage. Schmidt, in Germany, had earlier noted evidence based on inferior data suggesting a nonpotential part of the earth's field, but even this was incompatible with the observed air-to-earth electric current. These considerations also, strongly supported by men like Schuster abroad, led to expanded scope of the survey program, once under way, including major emphasis on the more difficult phase of ocean magnetic work.

In the enthusiasm of the time the question of a suitable laboratory for the new endeavor was deferred, with funds devoted rather to ocean work, and only modest quarters were occupied during the first few years. A wooden sailing vessel, *Galilee*, was chartered and modified to reduce the amount of magnetic materials near observing platforms, so that magnetic survey measurements could be undertaken. Three successful cruises in the Pacific were made during the years 1905 to 1908, but troubles due to magnetic materials within the ship were not completely eliminated. The effects of these magnetic materials upon measurements of declination, inclination, horizontal intensity, and total intensity of the earth's field varied with the time of cruise, roughness of passage, and geographical location. In the interest of economy and to improve the quality of the results, plans and specifications for a new nonmagnetic yacht, *Carnegie*, were drawn up in 1908. In December 1908, the Trustees made for this purpose what was

up to that time the largest special appropriation of the Institution, and the *Carnegie* was launched June 12, 1909, in the presence of 3500 guests. The total original cost of the ship fully equipped was \$115,000. Her early cruises were at once productive. Andrew Carnegie himself was so impressed during this period with the work of the Institution that he made available in 1911 a new and large appropriation. During the period from 1909 until her destruction by fire in 1929, the *Carnegie* made seven cruises covering all oceans, extending to the very boundaries of the north and south polar-ice areas. Together with those of the *Galilee*, these cruises totaled 361,413 nautical miles, and 3836 observations of magnetic declination and 2321 of inclination and horizontal intensity were made. Records were also obtained of atmospheric-electric potential gradient and conductivity. In addition, on the last cruise, extensive data relating to topography of the ocean bottom, oceanography, and the biology of the ocean were obtained and studied. The results have now been published in many volumes.

At the same time, the survey program on land was being vigorously pressed, with chief emphasis on South America, Africa, Australia, the islands of the various oceans, and, as opportunity offered, the polar regions. There were in all over a hundred expeditions, which yielded not only measurements at thousands of stations, but also intercomparisons and improvements of magnetic standards in other countries. Simultaneously, a laboratory program was begun which permitted extension to new work beyond that required for design and maintenance of instruments in the mainly observational program. This laboratory phase of attack on the two major background problems, the cause of the magnetic and of the electric field of the earth, became possible when the Department

moved to its present main building, completed in 1914 at a cost of \$68,000, on a site of some eight acres in suburban Washington.

Hopes for a vigorous laboratory approach were not realized in these earlier years. At that time the observatory program required the attention of most of the staff, and it was necessary to devote much effort to the design and maintenance of the requisite observing instruments. The organization of the observational material in final form was in itself no small task. By 1920, however, some theoretical investigations of the data accumulated had been carried out, and though the description of the earth's magnetic and electric fields had been much improved, no real clue had emerged leading to their explanation. Bauer showed that all except a small percentage of the earth's field was of internal origin. By this time a laboratory approach by Barnett had shown that a rotating sphere becomes magnetic, but that the amount of magnetization is far too small to account for the earth's main field. Other studies by Swann also failed to solve the problem. The observation of ions in considerable quantity over the oceans, even though sea water is considerably less radioactive than the ground, was one factor leading to the establishment of cosmic rays as of extra-terrestrial origin.

There was uncertainty as to what profitable course might next be followed in relation to the main field problems, which exist in no less degree today. There remained, however, a lingering hope and faith that the surveys would show in some way a profitable approach, perhaps by ascertaining the world-wide pattern of secular change, not then at all available, which could be compared with that of other geophysical phenomena of the earth's crust. The surveys were therefore continued, and on land were facilitated by

much greater and increasing participation by other organizations, stimulated by past endeavors of the Department.

The two riddles, the origin of the magnetic and that of the electric field of the earth, remained unsolved, with further progress difficult and uncertain. Because of dissatisfaction with prospects for rapid progress on these problems, attention was directed toward the more accessible magnetic and electric variations. In this way there arose the observatory program of the Department during the period 1916-1920, with particular emphasis on time variations. In an important sense, however, it was a continuation of the survey program, because the estimates of secular change depended for their accuracy on ascertaining and removing effects of magnetic variations recorded at observatories, and because it was possible only at the observatories themselves to obtain accurate estimates of secular changes.

The observatory program, 1920-1930. Following World War I, in which some of the staff were of help in the national crisis, perhaps most tangibly in the development of magnetic navigation for aircraft, and a little ahead of the times in the invention of the magnetic mine, ambitious postwar plans appeared for an observatory program. A good part of the staff formed a skilled and efficient data-gathering organization, and experience had already been obtained in operating magnetic and electric recording stations on a number of eclipse expeditions.

The initial plan for establishing nine magnetic observatories, mainly in the southern hemisphere, seems to have been withdrawn in the face of practical considerations, in favor of establishing one in Australia and one near the magnetic equator in South America, thereby materially improving the world network of observatories. Thus the observatory at

Watheroo, Western Australia, began operation on January 1, 1919, and that at Huancayo, Peru, on March 1, 1922. It has turned out that these choices of site were particularly wise and fortunate.

This period was, however, one in which there was at least an undertone of hesitancy in continuing the previous program, then already carried forward for nearly twenty years. In 1922 the main results achieved were reviewed by a distinguished group of scientists, a sort of informal board of inquiry. They expressed general satisfaction with results achieved, and noted that at least the observational aspects of terrestrial magnetism and electricity had been rescued from what had approached a state of chaos. It was decided to curtail survey activities, since other agencies were now active in such work, and to pursue the observatory approach, which promised a better chance of correlations with solar and other phenomena, supported by laboratory and theoretical studies related to these problems.

The observing programs at Watheroo and Huancayo included in the early years continuous recordings of magnetic field components, earth-current potentials, and the vertical potential gradient and conductivity, two of five desirable atmospheric-electric elements. The plans contemplated operation through a sunspot cycle. Valuable recordings of variations were obtained at these points, relatively remote from other observatories, which helped considerably, in conjunction with those from other stations, in providing descriptions of these variations on a world-wide scale. The high elevation of the site of the Huancayo station (11,000 feet) seems to have provided no great advantage.¹ The location of the

observatory, however, on the geomagnetic equator proved to be opportune, and it was a surprise to find that the daily magnetic variation was more than twice as large as expected. When explained in later years, this feature was to become very useful in attaining rather complete understanding of this variation. Occasion was also taken to obtain recordings at other sites, usually for a period of one year. In co-operation with the United States Coast and Geodetic Survey, earth-current and atmospheric-electric elements were simultaneously recorded for many years at Tucson, Arizona. During this decade the routine accumulation of observatory and survey data (including those for the more extensive program of Cruise VII of the *Carnegie*) all but swamped the facilities of the Department.

There were, however, new influences at work early in the decade, which were destined to affect profoundly the future development of the observatory program in an unexpected manner. The informal recommendation of the conference in 1922 that a mathematical physicist be added to the staff brought Breit to the Department. His first assigned task was that of examining the possible relation of the earth's main fields to the general theory of relativity, then comparatively new. It was quickly found that this line of investigation seemed unpromising, and the search for other problems brought the suggestion of estimating the height of the ionized layers in the atmosphere by means of radio waves. This resulted in the so-called Breit-Tuве experiment, in which a pulse technique was evolved for sending and recording the return of radio waves at vertical incidence. The time taken for the waves to reach the ionospheric layer gave an estimate of its height, since the velocity of the waves

¹ It was the intention to establish the observatory on the magnetic equator somewhere near sea level, but the magnetic character of all sites examined at or near sea level prohibited this.

High altitude was not regarded as being of any special advantage.

was known. Thus was developed a new technique for probing the upper atmosphere, which was much more analytical and unambiguous than the frequency-change interference method simultaneously developed by Appleton in England. This pulse technique also became important much later as a basis for engineering applications such as radar. Although the potentialities of the new technique in the study of geomagnetic variations were not overlooked, the resources of the Department seemed inadequate to explore the new possibilities. After three years this work was set aside, since the National Bureau of Standards was prepared to undertake a large program in the radio field. The Department's program was resumed about five years later.

Following the pulse experiment, research was undertaken with high voltages in an effort to study the forces involved in collisions between electrons and electrons, and between protons and protons. After some years the experiments resulted in the discovery of intense force fields in the neighborhood of the nuclei of atoms, and later in experimental confirmation of the fission of uranium. These laboratory experiments as such had little relation to the objectives of the survey and observatory programs, but they gave expression to the hope that a clue to the source of the earth's main field might be found among unexplored properties of the fundamental particles composing atoms.

In atmospheric electricity the decade 1920-1930 was marked by the discovery, based on studies of ocean electric measurements of the *Carnegie*, that the negative electric charge over the earth's surface as a whole varied periodically by about 30 per cent of its average magnitude each 24 hours, independently of local time. This result stimulated moderately successful efforts to identify thunderstorms as the

source of the supply current maintaining the negative charge of the earth, which otherwise would be reduced to a fraction of its observed value in a matter of minutes. This possibility is being checked in our present program, by attempts to measure the assumed current flow from thunderstorms up to the ionosphere, using instruments in airplanes flying above thunderheads.

Continuous measurements of vertical potential gradient and conductivity at the Huancayo, Watheroo, and Tucson observatories were studied. The results found, though interesting, were masked by uncertainties of various kinds due to local conditions, such as smoke from brush fires and smelters, and lack of local information respecting time variations in the amounts of large and small ions. It must now be acknowledged that the value of such records is uncertain in the absence of additional simultaneous measurements of the ionization of the air.

Two members of the Department, Gish and Rooney, introduced and developed early in this decade experimental approaches in the study of natural and induced earth currents. It was soon found that the time variations in earth-current potentials are probably adequately explained as produced by variations in geomagnetic fields of external origin. A practical technique of measuring earth resistivity was developed which is now widely used in geophysical prospecting. Apparatus for making continuous measurements of earth-current potentials were installed at Watheroo in 1923, Huancayo in 1926, and Tucson in 1931, and operated until 1946. The results confirmed the general qualitative agreement expected on the basis of electromagnetic induction, and were of interest in connection with certain electric-transmission and communication problems of engineering.

By 1932, attempts to discover influences of solar eclipses on geomagnetic fluctuations were abandoned. Some progress was also made in providing more precise information respecting the correlations of geomagnetic, auroral, and earth-current variations with solar phenomena such as sunspots, stimulating efforts of the following decade.

The evolution of the observatory program, 1930-1940. The magnetic survey of the earth was now beginning to provide a descriptive pattern of secular change. This pattern became apparent in the magnetic elements on a world-wide scale for the first time, and was shown on Fisk's preliminary isoporic charts for 1922, published in 1931. Although magnetic surveys on land were continued, mainly for the purpose of improving estimates of secular change, ocean surveys were perforce abandoned because of the loss of the *Carnegie*. Accordingly the observatory program received greatly increased emphasis and expansion after 1930. It was broadened to include measurement of variations of the electron density and heights of ionized layers of the ionosphere, first at Huancayo in 1932 and later in 1933 at Watheroo. Suitable practical and automatic apparatus was developed by Berkner and others to send radio pulses yielding echoes from the ionosphere which were continuously recorded at a wide range of frequencies. This multifrequency equipment was installed at both Huancayo and Watheroo by 1938, and at College, Alaska, in 1941. It was of particular importance in that it provided a record of events throughout the range of about 100 to 300 km and higher within the ionosphere, for study in connection with geomagnetic and other phenomena observed at ground level. Possibilities were further broadened by installation of a spectrohelioscope at each ob-

servatory, permitting direct observation of solar phenomena.

In addition, seismographs were installed and operated at Huancayo in 1932. A later feature was the installation of cosmic-ray meters at Cheltenham, Maryland, in 1935; Huancayo, Peru, in 1936; Christchurch, New Zealand, in 1936; Teoloyucan, Mexico, in 1937; Godhavn, Greenland, in 1938; and San Juan, Puerto Rico, in 1947. This was a co-operative observatory venture sponsored by the Cosmic Ray Committee of the Carnegie Institution. The previously inaugurated recordings of the atmospheric-electric elements and earth-current potentials were continued as sustaining programs, though expectations were limited. The expanded observatory program had thus become in effect a broad program in geophysics, although under the directorship of Fleming, who continued the policies of Bauer, the major emphasis was placed upon those theoretical aspects useful in explaining the geomagnetic variations.

On April 8, 1936, a brilliant solar flare, accompanied by a nearly simultaneous change in magnetic intensity, radio fade-out, and earth currents, was observed by Scott, Torreson, and Stanton. This was a direct linkage of a spectacular solar phenomenon with terrestrial effects, though it now appears that the classic observation was in fact a hitherto discredited one of simultaneous magnetic changes during a solar flare made by Carrington in 1859, and that Dellinger had already noted that solar flares were sometimes accompanied by radio fade-outs. Nevertheless, the noting of this effect was dramatic, and McNish quickly found that the solar flare was almost simultaneously followed by an augmentation of the daily magnetic variation on quiet days.

This essentially established the fact that, of several theories proposed to explain the

daily magnetic variation, the only one tenable was the dynamo theory of Stewart-Schuster, later elaborated by Chapman. According to this theory, the daily magnetic variation is caused by electric currents produced in a conducting layer of the atmosphere below the E-region (the region of the ionosphere about 100 km above the earth's surface) by the motion of the layer across lines of force of the earth's main field; the augmentation of the daily variation is of course due to the marked increase in ionization and consequent increased conductivity accompanying the burst of ultraviolet light from the sun during the solar flare. The radio fade-out is due to absorption of the radio pulses near or within the same conducting layer. The changes noted in earth currents are caused by the changing geomagnetic field. The dynamo theory also satisfactorily explains the particularly large amplitudes of the solar and lunar daily magnetic variations discovered at Huancayo, a consequence of the noncoincidence of the geomagnetic and geographic equators.

Chapman, a research associate of the Institution in England, and his students developed, but did not complete, a theory ascribing magnetic storms to effects of electrically neutral streams of corpuscles of solar origin. They also estimated possible electric-current patterns within the atmosphere which could produce the large changes in the geomagnetic field during storms, and roughly estimated the height of electric currents near the auroral zone to be about 100 km. Inconclusive study was also made of the possibility that a part of the storm field was due to an electric ring current encircling the earth at a distance of a few earth radii. It was not shown how the electric current patterns in the atmosphere could arise from neutral streams of corpuscles emitted by the sun. These findings were further clarified in

detail by various supporting researches carried out within the Department by McNish and Vestine. On the observational side, Berkner and Wells noted increases to 1000 km in the height of the F-region (the highest layer) of the ionosphere during magnetic storms, and Forbush discovered that a decrease in cosmic rays usually appeared during the main phase of magnetic storms. Neither of the latter phenomena is as yet adequately understood. Consequently, it would seem that much remains to be done before all the effects connected with magnetic storms are satisfactorily explained.

Bartels, in Germany, also a research associate of the Institution, carried out extensive statistical studies, and made basic improvements in statistical techniques of universal interest, in correlating solar and geomagnetic disturbance. He showed how geomagnetic variations could be used to indicate variations in solar ultraviolet light and corpuscular emissions, and devised new measures of geomagnetic activity, the so-called K-index, now widely used in the practical applications of radio communications. He also showed that the large lunar daily magnetic variation at Huancayo could be explained in accordance with Chapman's dynamo theory for this variation.

The data from seismographs installed in 1932 at Huancayo were not studied in the Department, but in the hands of Gutenberg and Richter of the Seismological Laboratory, Pasadena, were particularly valuable in defining the earthquake zones along the Andes and world epicenters, and in the discovery of a silent zone for shock waves propagated through the earth, indicating a zone of discontinuity or velocity change at a depth of several hundred kilometers.

There seems to have been no immediate necessity which dictated the inauguration

of the Institution's program of recordings of cosmic-ray intensity at several observatories. This was begun simply to obtain a continuous and world-wide picture of the variations of cosmic-ray intensity. The results found would be completely unexpected even today, on any reasonable basis within our experience. This program is hence a fine example of the truth of the proposition that in geophysical research long-continued recordings of a new geophysical phenomenon will in the end turn up something of value, and is in a measure a justification for the blind faith in this mode of attack in geophysics. By contrast, there was every reason why the Department should have begun its cosmic-ray program before 1920, when members of the staff had been for some years bewildered by the presence of ions in quantity over the oceans; this might have led them to pioneer the development of the field of cosmic rays.

The first important effect noted in the program of cosmic-ray recordings which began in 1936 was the decrease by as much as 10 per cent in cosmic-ray intensity during the main phase of magnetic storms. Examples were also found of intense magnetic storms accompanied by little or no decrease in cosmic-ray intensity. Attempts were made by Forbush, following Chapman, to explain this effect as due to decrease in the effective magnetic moment of the earth through the additive field of an equatorial ring current producing the main phase of storms, but this point is not yet established. A more spectacular finding by Forbush during the current year was that in about ten years of records there were three increases, one as great as 20 per cent, in cosmic-ray intensity during large solar flares. This suggests the sun and other light-emitting stars as the origin of cosmic rays.

The early recording programs in earth

currents and atmospheric electricity were continued after 1930. In regard to earth currents, adequate data were obtained in polar regions at College, Alaska, and Chesterfield, Canada, which permitted construction of a tentative map of general global circulation of surface earth currents. The existence of the detailed relation was confirmed strikingly by the parallelism between earth currents and geomagnetic variations during the large unexplained increase in activity just after the winter solstice near Tucson. These programs were terminated at the end of 1946, though a few supplementary measurements of missing particulars respecting ions were undertaken early in 1947 at Huancayo. The latter measurements may make it possible to interpret some aspects of the earlier continuous recordings.

Electrical measurements in the stratosphere on the balloon *Explorer II* showed need for some modification of commonly accepted propositions in physics respecting the dependence on pressure of the mobility of negative ions, and the recombination coefficient for small ions at lower pressures. A maximum in electric conductivity of the atmosphere was found at the height of 18 km.

The war program and the shift to governments, 1940-1947. World War II brought many highly technical developments into application, with a resultant demand for highly specialized geophysical information on an unprecedented and world-wide scale. It was hence natural that the accumulated data and experience of the Department should be brought into play in the application of geomagnetic and ionospheric knowledge to warfare. The main demand was for descriptive material and engineering developments.

The effective use of magnetic mines by Germany early in the war stimulated an active development program for various

kinds of magnetic mines and counter-measures among the allied nations. The sensitivities and types of mines chosen for development, and for use in various parts of the world, were of course to some extent limited by the natural geomagnetic fluctuations. K-indices for magnetic activity were also required in forecasting radio communication conditions. New and more accurate isomagnetic charts were required in navigation and in the degaussing of ships.

The Department undertook the compilation of existing data on all classes of geomagnetic fluctuations, and especially their frequencies and average magnitudes in all latitudes and longitudes, in a form suited for engineering applications. Of particular value in this undertaking were the micro-filmed copies of magnetograms of the International Polar Year, 1932-1933, and the scattered published results available in our rather complete library. This work considerably extended previous work in description of the geomagnetic variations. Also undertaken was the task of preparing new isomagnetic and isoporic charts. In this way the results of voluminous surveys on land and sea, made over many years by the Department and other agencies, were used in improving the description of the earth's main field and its secular change. In the process, the descriptive results of magnetic observations made at over a hundred observatories were derived and collated, for the various geomagnetic variations, in summarized form. This work was required for improving the isoporic charts, which in turn made possible more effective use of existing data in the preparation of main field charts. New survey data were obtained through the loan of magnetometers to other agencies, and magnetographs were built and installed at various locations to meet the requirements of the armed services. The

significant feature of this work was that its general objectives were defined by the government, which likewise provided under nonprofit contracts most of the funds for completion of the projects.

A similar condition arose in the radio field. In the case of the ionosphere, an urgent demand arose for information pertaining to radio communication in operational areas. This could be provided only by installation of additional ionosphere stations with multifrequency recording equipment. The Department activities supervised by Wells, included installation and operation of such equipment at Clyde, Baffin Island; Reykjavik, Iceland; Maui, Hawaii; Christmas Island; and Trinidad. Service personnel were trained to operate equipment at many other stations, including Guam, Okinawa, and Leyte. The Department's ionospheric station and magnetic observatory at College, Alaska, was likewise operated under government contract. The analysis of almost all ionospheric records obtained, including those for Huancayo and Watheroo, was undertaken by the Central Radio Propagation Laboratory, as was also the continuation of certain researches involving improvement of techniques of forecasting radio communication conditions initiated in the Department.

The temporary expansion of the Department by several fold in personnel and budget during World War II effectively emphasized the truth that modern survey and observatory activities are better undertaken by governments, rather than in part by a relatively small organization such as the Department of Terrestrial Magnetism. Accordingly, following the plans made nearly thirty years ago, in 1946 the Department's observatories at Watheroo and Huancayo were offered with complete complement of equipment, after some changes in program, to the respective gov-

ernments in Australia and Peru. Other survey and observatory activities financed by the United States government had been terminated at the close of the year 1946.

It should, however, be noted that both the survey and the observatory program were in fact continued considerably longer than was originally proposed. Our surveys over the oceans had stopped in 1929, and those over land in 1936. The original intent was to undertake observatory work in regions neglected by others for a period of one sunspot cycle, but, as previously mentioned, the appearance of new possibilities during the period 1920-1930 made it desirable to extend this effort over another similar period.

Summary of main ideas and results. Explanations of the earth's magnetic and electric fields were sought. In order that the picture of these phenomena might be brought into sharper focus, thereby better describing what it was sought to explain, a magnetic and electric survey of the earth was carried out. The world patterns of secular change were obtained for the first time throughout the period 1905-1945, and it was found that the electric field of the earth as a whole varies periodically every 24 hours by about 30 per cent. The search for the cause of these phenomena, however, was unsuccessful. By careful experiments Barnett showed that magnetization by rotation could not explain the earth's magnetic field, and a similar search by Swann, from a theoretical approach, proved likewise unsuccessful. The results of magnetic surveys, however, have been of great benefit in various practical applications of geomagnetism, and this work is now being extensively carried on by others. A high light of the ionospheric work was the development of the pulse experiment, which was elaborated later into the multifrequency technique for exploring the upper atmosphere. In

the atomic-physics program, verification and first measurements were made of the tremendous forces between protons and neutrons at very short distances, which are the forces that bind these particles to form atomic nuclei. Resonance energy levels for nuclear disintegration were also found and measured.

Among the more important of the terrestrial-solar phenomena, now better understood as a result of the Department's observatory program, were the following: determination that the daily and lunar geomagnetic variations are caused by the ultraviolet radiations from the sun and the motions of the upper atmosphere in the presence of the earth's magnetic field; closer linkage of specific (solar flare) and average solar conditions with variations in geomagnetism, the ionosphere, aurora, and cosmic rays; the rather complete description on a nearly world-wide scale of geomagnetic variations of various periods at different times of the sunspot cycle and their possible electric current systems in the atmosphere. The world-wide pattern of surface earth currents was estimated, and technique used in electrical geophysical prospecting was developed. The results of the observatory program were also useful in practical applications such as the improvement of radio communications on a world-wide scale.

Future importance of magnetic surveys and geophysical observatories. Surveys of the changing magnetic and electric fields of the earth, an important part of the human environment, should no doubt be continued, even after their causes have been satisfactorily ascertained. So far as we now know, magnetic secular change gives our only indication of rapidly changing processes deep within the earth's interior. There are also indications of slow trends in vertical conductivity of the atmosphere over decades of time. Hence

the continuity should not be lost between present-day and future descriptive knowledge afforded by such surveys.

It seems well to emphasize, however, that these surveys have greater potential interest if supported in other ways. There is little value merely in the making of measurements to preserve continuity of human record. The present-day effort should therefore be directed more searchingly toward explanations of the phenomena. Something will be learned from more ambitious world surveys of the gravitational field, and from seismic data, which like the geomagnetic field yield indications respecting the earth's interior. Finally, active laboratory and theoretical approaches should be sought in order that there may be desirable rapid evolution in the character of such surveys and in the understanding of their results. There is little point in too great detail, and in too frequent surveys. Although contributions along laboratory and theoretical lines can be expected from private institutions of research, the major survey activities can be effectively undertaken only by or with the continuous financial support of governments, upon which the responsibility ultimately must rest.

Local detailed magnetic surveys by airplane over areas of geophysical interest, such as volcanoes, or from ships towing survey instruments at considerable depth within the oceans, may be expected to yield results of future geophysical sig-

nificance. It seems likely also that electric surveys by airplane will contribute to the solution of some of the problems of atmospheric electricity.

It is our view that the future activities of geophysical observatories will be highly productive and significant. Magnetic storms and disturbances, not yet well understood, have recently been found associated in time with marked changes in the ionosphere and in cosmic-ray intensity, and these effects, also associated with auroral phenomena, are completely unexplained. There will no doubt be added recordings from time to time of new aspects of geophysical phenomena, using new techniques. Thus, installation of high-speed ionospheric and magnetic recorders, of enhanced sensitivity, is assured, as well as of more sensitive cosmic-ray meters, solar radio-noise recorders, and other instruments. Geophysical observations throughout the atmosphere using rockets are already being undertaken. There will be need to undertake these at many points over the surface of the earth. Unfortunately, a counterpart of this direct approach does not exist for probing the earth's interior.

In the promising future before those engaged in survey and especially in observatory work, the Department hopes as heretofore to make some contribution from time to time in the development of new techniques, in stimulating endeavor, and in the interpretation of measured results.

SUMMARY FOR THE REPORT YEAR 1946-1947

This first year of postwar operations marks a major change in the activities of the Department, with the completion of the observatory and field-party work of the world magnetic survey.

A survey of the situation at the end of World War II disclosed two things. First,

our two observatories had achieved worldwide recognition as stations of paramount importance in the uneven world distribution of observing stations, and were recognized as such by the governments and scientific agencies in their areas. Second, our own estimate of the status of the prob-

lems for which they were established indicated that the most striking puzzles connected with the earth's magnetic and electric properties might be approached *more fruitfully by attempting geophysical experiments of relatively limited duration than by expending most of the efforts of a small group such as ours on a program of continued observations.* Fortunately the governments of all nations are now much more alive to the importance of scientific activities, and the collection of geophysical data over long periods is widely accepted as an appropriate activity for a governmental scientific bureau. Accordingly, a decision was made to transfer by gift the entire establishment of the two observatories to the governments of Peru and Australia, respectively. This proposal was gratefully accepted as of July 1, 1947, and arrangements were made for the transfers.

In rounding out our activities toward the completion of this matured program, the publication of seventeen large volumes of data and interpretation was undertaken. Much of the work of computation and study had been done previously, and as the report year closes only minor editorial and assembly work remains to be completed on the last five volumes.

The Department now turns to a new emphasis on laboratory and experimental work. Much of this will involve field trips, of course, as the earth is too large and varied to be studied in one spot. Two outstanding problems remain unsolved by our past program, namely, the origin or cause of the main part (95 per cent) of the earth's very large magnetic moment, and the maintenance of the earth's electric charge in spite of the constant current of many thousands of amperes from the air to the surface of the earth. There are other striking problems relating to the physics of the earth, and there is ample precedent for our confidence that they are not dis-

connected, and that initiative in attempting new experiments and making fresh approaches will yield results of unexpectedly wide significance.

Most of our studies in the past have been concerned with descriptions of phenomena related to these puzzles, such as the small daily, annual, secular, and storm variations of the large and unexplained magnetic field, the contributions of the ionosphere and earth currents to these magnetic variations, and the behavior of ions and attachment particles in the air which participate in the air-earth current. Because these problems of magnetism and electricity embrace the entire solid earth and the atmosphere, and relate directly to some of the great fundamental questions concerning the structure of matter, there also have been vigorous thrusts in several other fields of physics, including studies in high voltages and nuclear physics. The Department is thus in reality a group of investigators trained in physical science concerned with certain specific aspects of geophysics and laboratory physics.

Bearing in mind the special character of the opportunity presented by the Carnegie Institution of Washington, with its unusually large freedom of objectives, and viewing the corresponding obligations which go along with this freedom, it is agreed that we must make every possible effort to emphasize creative work, ideas with new potentialities, and work which lies on the front lines of knowledge. The Institution has no external allegiance or obligations, no students, stockholders, voters, or other special groups to serve. This gives us an obligation to accept greater risks than others, and we should accordingly concentrate our efforts primarily on thrusting forward the very front lines of advancing knowledge. Every program should be scrutinized at regular intervals and pruned or reoriented to meet

this criterion; any new problems or interests or new men or activities should also be required to meet it. It is probable that the front lines of inquiry in many fields need to be more clearly mapped, in order that our efforts may be guided toward problems of importance in our time, in reasonable balance with opportunity, and with some hope of definite progress toward solution or toward new formulation—even failure has value.

There are serious restrictions as to possible size of staff and annual expenditures, and accordingly our program must be chosen with regard to its effectiveness as a stimulus or catalyst to the work of all other groups concerned with a given field. These considerations lead naturally to a major emphasis on co-operative endeavors, in which the Institution and the Department can be of great influence and value if we are capable of vigorous leadership in fresh and significant directions.

Plans for co-operative activities, in which other agencies play a larger part than the Department, in magnetic work, in exploratory geophysics, in laboratory physics, and in biophysics will characterize the entire program of the Department for the next few years as the staff now views it. For any one subject or project only a small group will be concerned here in the Department (often not more than two or three), and members of other organizations will participate as importantly in our projects as ourselves. True research, however—creative research—is always done in very small groups, rarely exceeding five or seven individuals. Hence this separation of the Department's staff, as in the past, into small discrete groups, with reasonable fluidity for shifts between groups, is regarded as both realistic and healthy. It is expected that particular attention will be paid to means for assuring the effective impact of young men on our staff leaders

and program. Our co-operation with universities and the resumption and expansion of the prewar program of Carnegie Institution fellows are of special importance in this connection.

The activities of the Department and the interests of the research staff divide naturally among three broad areas: (a) statistical and analytical geophysics, including observatory results, (b) exploratory geophysics, and (c) laboratory physics and biophysics. In the past the main emphasis of the Department has been in the first area, but it has been agreed, with the Department's observatory program already carried through two complete sunspot cycles, that there will now be a more general shift of emphasis away from this first area and toward the other two.

Our activities thus move toward those of a physics department with special emphasis on experiments in geophysics and biophysics, making intensive use of the techniques and ideas of modern physics. The biophysical program, which has evolved as a modest new outgrowth of our work in nuclear physics and our studies of the properties of the primary particles of matter, is directed toward studies of the fundamental physical properties of living matter, and is carried on as a joint activity with the many biological groups in the Washington area.

A surprising discovery was made during the year in the cosmic-ray program. Long-continued observations of cosmic-ray intensity have been made at various stations scattered over the earth during the past twelve years as a part of the Department's program. Variations of about 1 per cent due to atmospheric changes and decreases of a few per cent caused by the increased magnetic moment of the earth following magnetic storms have been regularly noted, but a pronounced solar flare and radio

blackout on July 25, 1946 was accompanied by a large *increase* in cosmic-ray intensity at all stations except at the equator, simultaneous with the flare and radio disturbance and lasting for several hours. A magnetic storm and its effects occurred as usual about a day later. The observations cannot be explained by the known change in the earth's magnetic moment due to ionization by ultraviolet light. It is difficult to see how the magnetic moment of the sun, usually assumed as the explanation of the cut-off of low-energy cosmic rays, can have been sufficiently altered by the flare effects to permit a "beam" of cosmic rays to pass by, although we are involved in calculations which it is hoped may settle this point. The only evident alternative is that the additional cosmic rays were produced by an accelerating action associated with the flare at or near the sun, possibly due to a local rate of change of magnetic field, as in a betatron accelerator. The origin of cosmic rays is so mysterious that a hint of this kind, associated with our nearest star and hence observable in some detail, with patience, is of the greatest interest. Search of the records showed two similar occurrences in 1942, or a total of three in ten years.

The measurements by Dr. H. W. Babcock, of the Mount Wilson Observatory, on the magnetic fields of the sun and of 78 Virginis have stimulated the British physicist Blackett to speculate again on the possibility that the earth's magnetic field represents a fundamental phenomenon in which the magnetic field is dependent on the mass and angular momentum of the body. There are other explanations of the earth's field which depend on complex internal phenomena in the core of the earth. Theoretical studies are accordingly being made in an attempt to link the rotation of astronomical bodies with convective motions producing internal electro-

motive forces and electrical current systems, such as those proposed by Dr. Walter M. Elsasser, of the RCA Laboratories at Princeton. To distinguish between these theories is of fundamental importance to geophysics and to physics as well.

The most fundamental lack is that of quantitative data on the behavior of the earth's field with time. Measurements of the faint residual magnetization of the annual layers of silt deposited by retreating glaciers at the end of the last ice age, about 25,000 years ago, were resumed during the year with results of striking interest. Just prior to the war these experiments had indicated that the deviation of the compass direction from true north had varied in a fashion similar to the changes observed during the past 350 years. Numerous tests this year have given strong evidence for the stability of this residual magnetization and hence for the reliability of these measurements as an indication of the compass direction in earlier epochs. In addition, new procedures have been developed, involving the redeposit out of a water bath in a magnetic field of the silt from single layers, which give a tentative measure of the *intensity* of the earth's magnetic field during that distant epoch. A preliminary determination of that intensity at the time of the last glaciation has now been made from clays collected at Bradford, Vermont. This measurement indicates that the earth's field has been unchanged in intensity for the past 30,000 years to within the accuracy of the measurement. The material used was shown to be able to carry the imprint of a field fifty times less or greater than the present value. The direction as well has remained substantially constant. The clays were collected in New England and were dated by the fine work of Dr. Ernst Antevs, former research associate of the Carnegie Institution. The interpretation of the polarization of the

clays was obtained only after long and tedious work in the laboratory, using the methods of modern physics. It is expected that the measurement of other clays will make it possible to extend this time scale to millions of years and thus to provide the quantitative data necessary to distinguish between conflicting theories. The experiments and observations are being continued, and some tests are under way with sedimentary rocks. There is a touch of romance in measuring a thing as subtle as the earth's magnetic field as it existed 25,000 years ago. If these studies can be successfully extended to rocks and hence to a vastly greater period of time, important limits will be set on theories of the earth's main field, a stupendous magnetic phenomenon which remains both a riddle and a challenge.

An interesting series of experiments using artificially radioactive tracer substances was carried out during the year by the cyclotron staff of the Department and their many colleagues in biology and medicine in the Washington area. Radioactive samples were also supplied to a large number of investigators in many parts of the world. The work here has been concerned primarily with studies of differential permeability and exchange through various membranes and cell walls in animals and in man. Although many of the observations, especially those related to the heavy metal compounds which were the war assignment of our cyclotron, are of immediate interest to medical men, our experiments and plans are directed toward

the fundamental physical properties of living systems.

The structure of the atomic nucleus offers another major problem. There is ample evidence that the nuclear constituents (protons, neutrons, and possibly alpha particles) are organized in some systematic way. This is shown in the distribution of the stable elements, the atomic masses, and many other properties such as spin (angular momentum) and magnetic moment. The system, however, is not known. The quantum theory used with such success in explaining the outer structure of the atom meets with great difficulty in the nucleus, first, because the forces are not known, and second, because the approximations used in the electronic structure are not possible in the nucleus, where many particles are interacting. In view of these difficulties a model of the nucleus based on similarity to a liquid drop has been found useful in some cases. This, however, gives only a rough approximation and fails to predict the periodicities of nuclear structure. Measurement of the angular distribution of the particles emitted in nuclear reactions gives a critical test of the theory of nuclear structure. During the past year the electrostatic generators have been used to study the light elements, and the cyclotron the heavy ones. The results obtained show that even the light elements (lithium and oxygen) are not simple in structure. Nor is the behavior of heavier elements (aluminum, copper, and gold) predictable from the liquid-drop model.

THE OBSERVATORY PROGRAM

Preliminary negotiations looking to the shift of the observatories at Watheroo and Huancayo to the governments of the countries in which they are located were initiated before the end of the previous report

year. As the decision to move forward rapidly with this transfer crystallized early in the report year, conferences were held regarding the appropriate balance and emphasis of activities at the two observatories,

to insure that a modernized program, well focused on areas of future importance, would be under way before the observatories were transferred. It was clear from the start that the magnetic observations were important and were well carried out, although it was found desirable to institute one or two changes in instrumentation. The radio observations on the ionosphere and radio field-intensity recordings were also considered basic. The present equipment for ionosphere studies has been in operation for many years, and initiative was taken looking toward the availability of new equipment for each station within the next several years, under the new sponsors. The present shortage of equipment, and the high costs of manufacture, prevented its prompt acquirement. The seismic, meteorological, and cosmic-ray programs at Huancayo were of clear importance, and are in a healthy state, and the spectrohelioscope observations at Watheroo fill a gap in that world program. The spectrohelioscope at Huancayo was recalled for overhauling.

Careful consideration was given to the expected future value of the atmospheric-electric program. Observations of potential gradient and conductivity had been made at each observatory over a period of more than twenty years. Study of these data confirmed our earlier convictions that atmospheric-electric measurements near the ground are largely a reflection of local circumstances, being affected by dust, smoke, and weather, and that any reasonable understanding of the detailed processes involved would require separate added registration of large ions, small ions, rate of ionization, and other variables. Expansion of the atmospheric-electric program to include these items, though interesting, would at most result in a better understanding of detailed local processes near the ground. Accordingly it was de-

cided to stop all registrations of atmospheric-electric components near the surface of the ground and turn to specific experiments, probably higher in the atmosphere, for further understanding of atmospheric-electric problems. In order to permit better interpretation of the existing records, however, the decision was made to record the additional elements above indicated for a period of a few months at Huancayo, and these observations were started in the late spring of 1947.

Similar critical examination was given to the earth-current program. During many years of observation at our two observatories and elsewhere, ample evidence accumulated to show that the residual earth currents which can be separated from local phenomena connected with the ground electrodes could be accounted for almost entirely as induced currents in the earth brought about by the changing magnetic field, which field in turn arises from variable currents of rather large magnitude in the ionized upper atmosphere. No evidence was found, nor could it be expected from the physical dimensions of our installations at the observatories, for electrical currents within or below the earth's crust arising from internal causes, as these are at best indistinguishable from electrolytic activity at the grounding electrodes. Magnetic observations at the earth's surface are a more convenient and more analytical measure of the variable currents in the upper atmosphere. Accordingly, the decision was made to stop the earth-current registrations at both observatories. In their place, an effort to devise new experiments, better suited to exploration of electrical conductivity and currents, especially in the deeper layers of the crust, would be made by the laboratory group.

The war activities of the Department relating to world-wide studies of the ionosphere, which involved the installation and

operation of ionospheric observatories at a number of places beyond the continental limits of the United States, have now been transferred to the newly organized Central Radio Propagation Laboratory of the National Bureau of Standards. Since world-wide interest in automatic multifrequency recording has led to the development of organizations such as this and other national laboratories to deal with these problems, it has also been decided to encourage these organizations in the analysis of ionospheric data so that the Department may concentrate its efforts on pioneering research with a view to developing otherwise untouched aspects of the field. With the transfer of responsibility, the decision has been made to redirect the Department's activities in upper-atmospheric research toward experiments designed to answer specific questions regarding the ionized layers. As a consequence, in the future the ionospheric data from Watheroo and Huancayo will go directly to the Central Radio Propagation Laboratory, which is in effect a world center for such studies.

Despite its small size, the Department of Terrestrial Magnetism, in part by reason of its connection with the *Journal of Terrestrial Magnetism and Atmospheric Electricity*, has served as an informal world center for studies of the earth's magnetism. The standard of observatory measurements maintained at Watheroo and Huancayo and the Department's instrument program during the first two decades resulted in world-wide intercomparisons against our instruments, making them informal world standards. With the loss of the *Carnegie* most of our important activities in world-wide survey work were brought to an end, although land parties continued for a few more years. When our two observatories were transferred to government operation, it seemed best to transfer at the same time

to the United States Coast and Geodetic Survey any functions needed for a center of information and activities connected with terrestrial magnetism. Appropriate discussions were held, and the Director of the Coast and Geodetic Survey willingly accepted the responsibility for enlarging its co-operative activities connected with arctic and antarctic expeditions, aerial surveys, magnetic standards, and correlation of world-wide results in appropriate simple tables. The Department will continue to foster the exchange of information, working closely with the Coast and Geodetic Survey, and loans of our equipment for expeditions and observatories, together with arrangements for use of our absolute magnetic standards, will be made through that agency.

HUANCAYO OBSERVATORY

The geomagnetic, ionospheric, seismic, and meteorological programs were maintained at the Huancayo Observatory during the report year. Fast-run magnetic recording with the la Cour magnetograph, and spectroheliograph observations of the sun's activity with the Hale instrument, were discontinued on July 31, 1946, and the atmospheric-electric and earth-current recorders were discontinued at the end of 1946. The weekly radio-telegraphic reports of K-indices were terminated at the same time. A complete reduction and tabulation of the final hourly values for all three magnetic elements beginning with September 1946 was undertaken at the Observatory instead of at the Washington office. Attention was given to the appointment and training of new Peruvian personnel and to problems connected with the expected transfer of the Observatory to the Peruvian government. Plans and estimates for new buildings on the Observatory property were prepared. The Institution provided

funds for a guest house for future visiting investigators from all nations.

In March 1947 W. D. Parkinson arrived at the Observatory from Washington to undertake special observations in atmospheric electricity, particularly in connection with the study of ion content and distribution in the air and its correlation with atmospheric conductivity.

WATHEROO OBSERVATORY

The geophysical program of observation and recording of geomagnetic and ionospheric data was continued throughout the year. Recordings of the atmospheric-electric elements were discontinued at the end of 1946 after a continuous series over 24 years had been obtained. The earth-current recorder remained in operation but the values were not tabulated. The reduction of the magnetic scalings to absolute values was undertaken at the Observatory throughout the report year. Current ionospheric data were supplied, as in previous years, to the Radio Research Board, Sydney, and the Central Radio Propagation Laboratory in Washington.

The Institution provided funds for a building for housing guest investigators. Additional staff quarters also were planned and partly constructed, as part of the program under the Australian government.

The Observatory was transferred to the Australian government as of July 1, 1947, and will continue to operate under the auspices of the Bureau of Mineral Resources, of the Department of Supply and Shipping.

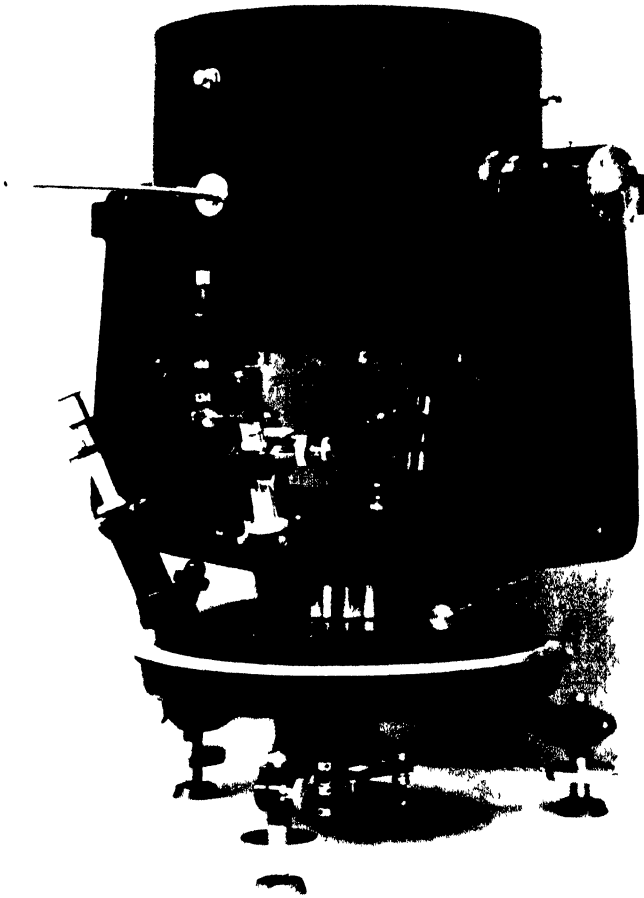
PRIMARY STANDARD

For many years the Carnegie Institution of Washington has played a leading international role in developing and maintaining the magnetic standards of the world, both by the construction of many of the

magnetometers used in field measurements and by comparisons of observatory standards. The last primary standards built are now nearly thirty years old. In anticipation of the grave need of maintaining the international standards and of obtaining international agreement on the value of the gamma, the previous Director, John A. Fleming, initiated in 1934 the design of a new primary standard of great accuracy. This standard has now been completed. It permits, for the first time, the measurement of any component of the earth's magnetic vector, although it is principally designed for the measurement of H , Z , D , and I . Its constant is determined by the mutual inductance between a primary coil and a rotating secondary coil. The absolute value of this coil constant is known to three parts in a million. It is expected that this coil will be used by the United States Coast and Geodetic Survey and that when its operation is satisfactory, it will provide a firm basis for the adoption of a standard value for the gamma.

PUBLICATION OF OBSERVATORY AND FIELD OBSERVATIONS THROUGH 1946

A necessary and interesting duty connected with the termination of the Institution's observatory and field-survey programs was the preparation during the year of a great volume of observations for publication—preparation much delayed by World War II. Previous volumes have covered the results obtained on the ocean surveys by the *Galilee* and the *Carnegie*, and numerous scientific papers have been written on the basis of the observatory records. Nevertheless, further study and discussion of this tremendous amount of material was appropriate, and its publication in a form to permit analysis by other groups was an obvious duty.



New absolute standard for magnetic fields built by the Department of Terrestrial Magnetism. Construction was begun in 1938 and was completed in 1947 after interruption by the war. Current coils mounted in grooves on pyrex glass cylinder are accurate to 0.00001 inch. This instrument will be used by the United States Coast and Geodetic Survey for international calibrations. It is accurate to about three parts in a million.

Early in the report year it was decided that the results of researches in terrestrial magnetism, ionospherics, cosmic rays, atmospheric electricity, and earth currents would be presented in tabular form in seventeen volumes totaling approximately 10,000 pages. Several thousand pages of tabulated data were already in hand at the beginning of the report year, and in the ensuing eight months some 7000 additional pages of data and text were prepared by a team of typists and tabulators. Miss Walburn, of the Office of Publications of the Institution, has assembled the tabulated data into suitable groups for publication in separate volumes, staff members have provided manuscripts, and suitable drawings and photographs have been prepared. During the year six volumes of results have been completed: two containing the magnetic results from Watheroo for the years 1919 through 1944, a volume descriptive of the earth's main magnetic field and its secular change for the period 1905 to 1945, a volume presenting the Tucson Observatory earth-current results for the period 1932 to 1942, the land and ocean magnetic results for the period 1927 to 1944, and ionospheric results from College, Alaska, for the period 1941 to 1946, a total of 3163 pages. Manuscripts for eight additional volumes have been prepared, covering work on geomagnetism, the ionosphere, earth currents, and atmospheric

electricity at various observatories, including Watheroo and Huancaayo. These require final editing, with the associated tabular data, and final layout for publication. Most of the work has also been completed for the remaining three volumes of the complete series; these will present observatory results on cosmic rays, earth currents, and atmospheric electricity.

In connection with this massive publication program it was acutely realized that the manpower requirements and costs of complete publication have become so prohibitive for continued observatory work in geophysics that a new approach is necessary to insure that data of this kind become accessible for study without waiting for final publication. Accordingly, recommendations were made at our two observatories for relatively prompt publication of the vital summaries of their observations using microfilm techniques, and a suggested small list for world distribution was prepared. The Institution may use this procedure in presenting some of the volumes in the above-mentioned list, particularly those of a specialized character which will be studied and used by relatively few groups throughout the world. It is believed that microfilm is destined to become an increasingly important vehicle for communication in specialized fields, although it cannot entirely replace the delayed complete publication of tabulated original data.

EXPERIMENTAL AND ANALYTICAL GEOPHYSICS

The Department's research in experimental and analytical geophysics is directed toward four principal aspects of the whole field, namely, (1) studies of the earth's crust, (2) studies of the upper atmosphere, (3) cosmic-ray research, and (4) analysis.

STUDIES OF THE EARTH'S CRUST

The earth is such a large and massive body that none of its physical characteris-

tics is changed appreciably within the lifetime of a single individual. Its surface cools and heats so slowly and imperceptibly that it is difficult to tell whether we are entering or leaving an ice age. Its magnetic field has such slow and imponderable changes that it is only with difficulty that we are able to ascertain whether or not the main dipole field of the earth is indeed changing. The earth has such great non-

uniformities in the small part that is available on the surface, and it is so difficult to reach very deep into its interior, that the problem of determining its physical structure and its physical history is almost unsolvable.

In the new exploratory approach of the Department to the geophysics of the solid earth there are two main parts. The first is to determine its physical history by reading the record of this history from the evidence of the crust itself; the second, to penetrate as deeply as possible beneath the surface in order to determine its internal constitution. Such an exploratory program requires both an expensive field examination of the earth by extensions of the already developed techniques of geophysical prospecting and the development of new ones, and laboratory verification of the theories required to explain the field data.

Three main problems are now in view. The first concerns the magnetic history of the earth; the second, the strength and structure of the earth's crust to great depths; and the third, the conductivity and the temperature of the crust to great depths.

The magnetic field of the earth as it now exists can be described with some accuracy. The origin and nature of most of its short-time fluctuations are well understood, and many of these can be predicted reasonably well. These fluctuations, however, are merely small perturbations of the main dipole field of the earth, and the cause of the main field is as much a mystery now as it was a century ago. There appear to be two possibilities. The first is that the cause is complex, the field being due to some fortuitous combination of circumstances which can produce circulating internal electric currents. For example, viscous flow of the interior matter of the earth might bring about temperature gradients, and these by reason of dif-

ferences in thermal electric power might cause circulating electrical currents deep in the core of the earth, and might have, in spite of the statistical nature, a remaining effect large enough to cause the earth's observed field. The other possibility is that the existence of a magnetic field is a fundamental property associated with large rotating masses. If this were so, then all the planets, and all stars, including the sun, should also be large magnets, with a magnitude depending upon their mass and angular momentum.

The evidence for either set of theories is at present scanty and full of contradictions. Accurate knowledge of the history of the geomagnetic field might go far toward distinguishing between the two sets. The historical data available, which go back about 350 years, are not adequate for this, because the massiveness and conductivity of the earth prevent any appreciable change from occurring in much less than 10,000 years.

If the first theory is correct, then it would not be unexpected if the dipole field were to change drastically with time or even to reverse. Historical evidence indicates that the field is decreasing at the rate of 4 per cent per century. If this were really so, in 1500 years the earth would have no field left, and on the other hand the field 30,000 years ago would have been 12 gauss. It is, however, uncertain whether or not the historical measurements are of sufficient accuracy to detect such a small change.

Before the war the Department made a small beginning in the measurement of the glacial clays of New England to determine whether or not the earth's field had indeed changed. An attempt was made to deduce, from the polarization of the clays, the direction of the field at the time when they were laid down. This was made possible by the development of

an extremely sensitive apparatus which extended the previous sensitivity measurement by a factor of 100,000. The results showed that in direction at least, the field was substantially similar to that of today, the variations in direction amounting to $\pm 30^\circ$, a variation similar to that observed historically. These measurements have

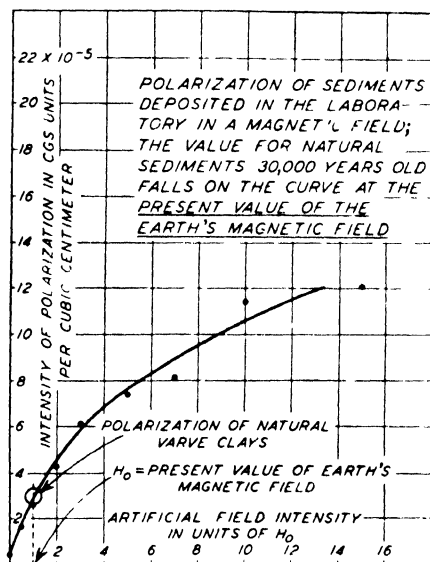


FIG. 1. Studies of ancient clay deposits have shown that the compass varied around a northerly direction, and the strength of the earth's magnetic field during the last glacial period was the same as it is now.

now been extended to cover an additional 2000 years of the 6000-year chronology established by Antevs, beginning about 2000 years after the period measured before the war. The results are similar to the prewar measurements: there is an indication of a 300-year period in the variation of the compass.

The most important and significant results, however, have been obtained in the determination of the intensity of the field.

The clays are best suited for this purpose, since their magnetization is very simple and can be reproduced in the laboratory. The intensity of the field at the time the clays were laid down was deduced by measuring the polarization of the same clays redeposited in the laboratory with various field strengths. Thus was obtained a curve relating the intensity of the field in which the clays were deposited and the polarization of the freshly deposited clay. For measurements of the clay *in situ* the average intensity about 30,000 years ago was determined to have been about the same as that of the present geomagnetic field within 10 per cent. The historically measured change in the earth's dipole moment can therefore be considered to be due either to inaccuracies of measurement or to a small and insignificant perturbation of the main dipole moment. The evidence thus does not eliminate the possibility that magnetization of the earth is not due to an inherent property of all rotating matter. The results are as yet preliminary, the question of geologic stability has not been satisfactorily answered, and the time scale is too short to draw final conclusions.

Unconsolidated clays are available which cover a time scale of millions of years, and are capable of yielding information on the intensity of the geomagnetic field over this same period. The sedimentary rocks probably contain reliable information on the direction of the earth's field, although at present it does not appear that intensity can be deduced from their polarizations. Only a few of these have been measured, and they indicate that the field has remained substantially constant in direction for many millions of years. There is every expectation that the completion of this research will yield a reliable history of the earth's field and thus provide the basic numerical data against which the two sets of theories may be tested.

Problems relating to the strength and structure of the earth's crust to great depths have occupied geologists and physicists for two hundred years, yet many simple questions remain unanswered, because so few observational and experimental techniques are available for obtaining information concerning the regions even ten or fifty miles below us. Monumental labors in geodesy have limited the acceptable hypotheses, and seismology has greatly increased our knowledge, especially of the deeper regions and the central heavy core, during the past three or four decades. Nevertheless we have but scanty knowledge of the structure of the granitic and basaltic layers which comprise in general the upper 50 km of the crust. Evidence from gravity measurements shows that great blocks of the crust are essentially supported by "floating" at about the 100-km level, but above this level our knowledge of their rigidity and strength, and even their density distribution, is largely hypothetical. Some mountains appear to have "roots," and others not, and we are still uncertain regarding the processes giving rise to mountain ranges, which have arisen many times in geologic history and are still evolving.

Records of near-by earthquakes have been the chief source of data concerning the granitic and basaltic layers which underlie the thin sedimentary rocks. In recent years a few observations have been made on the earth waves produced by explosions, and the large surplus of TNT remaining in the hands of the government after the recent war may provide an opportunity to explore these layers by controlled experiments. A request was made to the United States Navy by the Institution for help in a series of measurements of this kind to be sponsored by the Geophysical Laboratory and this Department with a group of university investigators,

starting with Columbia University and the New Mexico School of Mines. Preliminary observations have been made on a series of small shots, chiefly for purposes of instrument development, and as the report year closes portable instruments for eight to ten observing stations are being completed. It is hoped that arrangements can ultimately be made to carry out observations of this kind in a number of regions of particular geologic interest, including the Appalachian range, the Canadian shield, the Caribbean, the Mississippi Valley, and selected parts of the Rocky Mountains.

One purpose of taking initiative in this direction, perhaps of greater importance than the expected observations themselves, is to interest a wider group of young students in scientific geophysics, and to bring fresh curiosity and imagination to the problems of everyday geophysics. Terrestrial magnetism is only one of these puzzles. New ideas and facts about the earth are of great human significance, and touch on man's philosophical relations in much the same way as astronomy.

A third problem which has been given only preliminary consideration involves the determination of the conductivity of the earth in a single bold, large-scale measurement of the deep conductivity. This has been considered in co-operation with Professor Slichter, of the University of Wisconsin, and the Office of Naval Research. Its aim is to estimate the conductivity and thereby the temperature of the deeper rocks of the crust, since the conductivity is highly dependent upon the temperature. The method involves the use of a number of mine-sweep generators which can be borrowed from the Navy, together with a great amount of heavy copper cable, forming a loop through which heavy pulses of current can be passed. The magnetic field produced by

this loop will depend upon the conductivity and the susceptibility of the underlying rocks. It is hoped that significant results can be obtained down to a depth of 15 to 20 km, but the experiment will be both costly and difficult in so far as the experimental techniques are concerned. The necessary generators and cables have already been set aside by the Navy.

STUDIES OF THE UPPER ATMOSPHERE

Research in geophysics of the upper atmosphere is of continuing interest to the Department. Following the suggestion of early investigators that the transient changes of geomagnetism were the result of the flow of electrical currents in the atmosphere, it was natural that the Department should turn to direct experiment to examine and expand these hypotheses.

The evolution of the Department's program of upper-atmospheric research as our knowledge of the atmosphere has expanded is worthy of emphasis. Commencing with the original pulse-echo experiments in 1925, which demonstrated the existence of ionized regions of the atmosphere and measured their heights, the Department's research turned to the development of this technique and application of it in automatic recording systems and methods. These methods produced curves from which the distribution of ionization could be directly deduced, and provided continuous information on ion distribution through the atmosphere.

These methods have now been generally adopted by observatories everywhere over the earth. As the mass of data has accumulated, the general structure and many of the principal phenomena of the outer atmosphere have become evident. With the wide use of these techniques especially under the impetus of World War II, the earlier objectives of the Department are

now in view. It has seemed profitable, therefore, to reorient the upper-atmosphere program toward examination of special geophysical problems, with expectation that such research would form a stimulus to further evolution of the world-wide program.

The basic geophysical questions concerning the outer atmosphere are: (1) What are the elementary particles of which the outer atmosphere is composed, and how do these vary with time? This question relates not only to its chemistry and the proportions of chemical elements at the several heights, but also to products of photochemical reactions of dissociation from molecular to atomic states, and the ionization products of ultraviolet light and energetic corpuscles. (2) What is the density, pressure, and temperature of the atmospheric envelope and of its constituents at the several heights to its outer limits? (3) What are the regular and irregular movements and flows of the atmospheric gas? (4) What external agencies, either hard or soft electromagnetic or corpuscular radiations, influence the structure and constitution of the atmosphere? (5) What can be inferred of the nature of these external agents from a knowledge of atmospheric fluctuations, especially where evidence of these agents cannot otherwise be observed from the earth's surface?

The present world-wide program of automatic recording and observation insures significant progress toward solution of some of these general problems in the foreseeable future. Nevertheless, the techniques at hand do not provide enough information to answer adequately the questions proposed above. The Department is therefore undertaking the development of promising new methods for attacking these problems, with the expectation of substantially advancing the state of our

knowledge. Four general modes of attack seem feasible and profitable for an organization of our size: (1) the adaptation of radio methods to entirely new kinds of measurement; (2) spot measurement using rocket techniques in co-operation with other agencies; (3) aircraft measurements of atmospheric electricity at the limits of aircraft altitudes; (4) analytical deductions based on the expanded experimental evidence. These approaches are complementary: the rocket measurements make possible checks and absolute values not easily obtained by the radio methods, whereas radio methods permit measurement of time changes not possible with rockets. By use of these approaches, together with the more general mass of data becoming available, it seems reasonable to expect that a further real advance can be made.

The work of the Department in this field during the past year has been primarily concerned with the reorientation of its program toward such special experiments. A substantial change in its physical plant has been involved, with transfer of its field facilities at Washington from the Kensington Experimental Station to the new Derwood Experimental Laboratory and with the physical development of that laboratory. The end of the year has seen the Derwood Experimental Laboratory completed to the point where effective experimental work can be commenced; in fact, much has been done in a preliminary way as the several parts of the laboratory were made available.

Staff discussions were fruitful in outlining a general field of interest and in formulating certain specific experimental projects. The following projects have been initiated during the report period.

Radiofrequency noise from the sun. Confirmation of the arrival of radio noise signals from the sun on a frequency of

200 Mc/sec was obtained May 28, 1947, using some modified components from war surplus radar sets. Signals dropped to a low level when the directional antenna was pointed away from the sun. On a radio receiver the solar "noise" sounds very much like the internal set noise heard when the receiver is operating at high sensitivity. This is known to fluctuate with varying solar activity and to depend to some extent on the recording frequency. The objective of the research program is to obtain precise measurements of solar noise intensities and other characteristics at frequencies of 200 Mc/sec and lower. Results of the program are expected to contribute to basic knowledge of solar activity, the gaseous solar envelope, and the fundamental problem of existence of a solar magnetic field—a matter which is open to speculation. Progress is being made in design and assembly of instruments for an attack on this problem.

Measurement of solar noise may also be expected to aid in understanding of the mechanism responsible for some sudden and striking increases in cosmic-ray intensity. These appear to be due to acceleration of charged particles by some process on the sun during violent solar flares. The intense cosmic-ray increase of July 25, 1946 coincided with a great increase in solar noise. In addition to providing further evidence on the correlation between the two phenomena, the polarization of the noise measurements may be useful for determining the rate of change of magnetic flux near the sunspot. This would indicate whether the consequent electromotive force could supply the energy for the cosmic-ray increases.

Thunderstorm project. This program is directed toward an answer to the fundamental questions, Why does the earth have a negative charge, and how is it maintained? Measurements of atmospheric

conductivity and potential gradient made during airplane flights above representative thunderclouds may prove or disprove the theory that electrical current flow upward to the ionosphere from the many thunderstorms scattered over the earth's surface is sufficient to maintain the earth's negative charge.

Co-operation of the United States Army Air Weather Service is assured, and close liaison is maintained with the Thunderstorm Advisory Committee. Arrangements are made for installing the instruments in airplanes capable of flying over thunderclouds and for conducting experimental flights during the late summer of 1947, using headquarters of the Thunderstorm Advisory Committee, Wilmington, Ohio, as an operating base.

The instruments have been completed and preparations are made for construction of additional units as required.

Fine structure of ionosphere. The panoramic recorder which was used to make the first motion pictures of ionospheric changes was loaned to the Central Radio Propagation Laboratory, National Bureau of Standards, in January 1947. A fire at the Sterling Field Station had damaged the Laboratory's ionospheric recording apparatus and left it temporarily without adequate means of maintaining the continuity of ionospheric data for the Washington area. The DTM apparatus was returned in June 1947 to our Derwood Experimental Laboratory, where it is now being installed.

Preparations are made for completing the developmental work on this apparatus and for obtaining a representative series of high-speed motion picture recordings of ionospheric disturbances such as the radio fade-out, sporadic E, magnetic storm effects, and similar phenomena. The detailed information on rapid changes and fluctuations of the ionosphere which is

obtained with this unique experimental tool should make new data available as a basis for the interpretation and understanding of many fundamental physical processes in the earth's outer atmosphere. One of the main questions of current interest is whether part of the ionization which causes a radio fade-out within a few minutes after the observation of a solar flare is due to particles from the sun traveling at roughly the speed of light. This is of special interest in connection with the cosmic-ray increases described elsewhere in this report.

Upper-air rocket experiments. New opportunities for direct measurements in the region 100 km or more above the earth have been opened by the experimental firing of the V-2 and other rockets by the armed services of the United States. Members of the Department's staff had close wartime connections with this work, and have participated in the evolution of these experiments and the associated scientific programs. One experiment which is closely related to our interests concerns the direct observation of the large electrical currents which circulate in the upper atmosphere and cause magnetic variations at the surface of the earth. Attention has been given to preliminary designs for apparatus to record the magnetic changes expected when a rocket passes through and above a current sheet in the ionized regions. This would be of great interest in locating the level of the currents causing diurnal variation, which latter changes greatly with location, and would be of very special interest if a rocket could be fired during a magnetic storm. Further development of this project, in co-operation with the Navy and the Applied Physics Laboratory of Johns Hopkins University, is anticipated during the coming year. Other closely related projects may be undertaken later in 1947 with the availability of additional

personnel and greatly improved laboratory facilities. These include (1) measurement of the earth's magnetic field in the ionosphere by radio methods, and (2) experimental measurements of the lower ionosphere. These experiments may be expected to help fill in existing gaps in the composite picture of our knowledge of the upper atmosphere.

In general the over-all research plan is to undertake specific experimental investigations on lines which are not being followed by other agencies or which will supplement and extend work under way in other organizations. Planning is left sufficiently flexible to permit the active prosecution of fruitful developments such as may occur during the execution of a research program and often lead to results exceeding in importance the original objectives.

A large percentage of the activities of the Upper Atmospheric Section during the report year has been devoted to reconversion—terminating the wartime (and pre-war) activities and starting on a new program. War contracts with their final reports were concluded late in 1946. The publication program of the Department has involved preparation of texts for several volumes of data, as detailed in another section of this report.

Close liaison and active participation have been maintained with organizations having common interests, such as the Joint Research and Development Board, Central Radio Propagation Laboratory, Institute of Radio Engineers, Applied Physics Laboratory, National Geographic Society, and other private or governmental organizations. Formal and informal conferences with domestic and foreign investigators have been stimulating and beneficial. The Department has been represented at meetings of the principal technical societies, and papers have been presented whenever ap-

propriate. Publications are listed in the bibliography.

COSMIC-RAY RESEARCH

Probably the most valuable observations resulting from some ten years of continuous registration of cosmic-ray intensity at four or five stations, heretofore sponsored by the Institution's Committee on Coordination of Cosmic-Ray Investigations, are of three sudden increases in cosmic-ray intensity. Increases similar to those for Cheltenham, Maryland, were observed at Godhavn, Greenland, and at Christchurch, New Zealand. All three increases began almost simultaneously with unusually long and intense radio fade-outs and solar flares or chromospheric eruptions. The cosmic-ray increases were similar and simultaneous on the day and night side of the earth. Magnetograms from several magnetic observatories indicate that the increase in cosmic-ray intensity cannot be ascribed to changes in the earth's magnetic field due to magnetic storms. Though the increases in cosmic-ray intensity might be ascribed to changes in the sun's general magnetic field, which might permit more cosmic rays from outer space to reach the earth, such a mechanism should be equally effective whether the solar flare occurred on the front or back side of the sun, yet only these three have been observed, all associated with flares toward the earth. Cosmic rays are regularly observed to decrease during magnetic storms.

The implications of this discovery of abnormal increases in world-wide cosmic-ray intensities during a few great isolated solar eruptions are, of course, outstanding in importance. The observation suggests that a changing magnetic field associated with a sunspot or flare may act as a magnetic accelerator giving cosmic-ray energies to charged particles. Similar processes on

or near many stars might then account for all cosmic rays. The question naturally arises: Are there cosmic-ray increases dur-

tion, a detailed study has been made to determine requirements for coincidence counters and large ionization chambers with sufficient sensitivity and low statistical fluctuation to show the fine structure of cosmic-ray activity without ambiguities arising from the production of "bursts" due to nuclear processes produced by cosmic rays when they strike our atmosphere or materials near the recording instruments. Assembly of a very large cosmic-ray ionization chamber for this purpose is progressing.

In order to provide material for statistical investigations of cosmic-ray variations through one sunspot cycle, much of the effort during the report year has been devoted to the reduction of data from continuous records. Since the work was interrupted by war research, some five or six years of records have accumulated from four stations. The reduction of all the original records is now complete at least through 1945, including tabulated bihourly means of cosmic-ray intensity corrected for barometric pressure for Huancayo from June 1936 through December 1945. Except for completion of the typing, the Huancayo data are ready

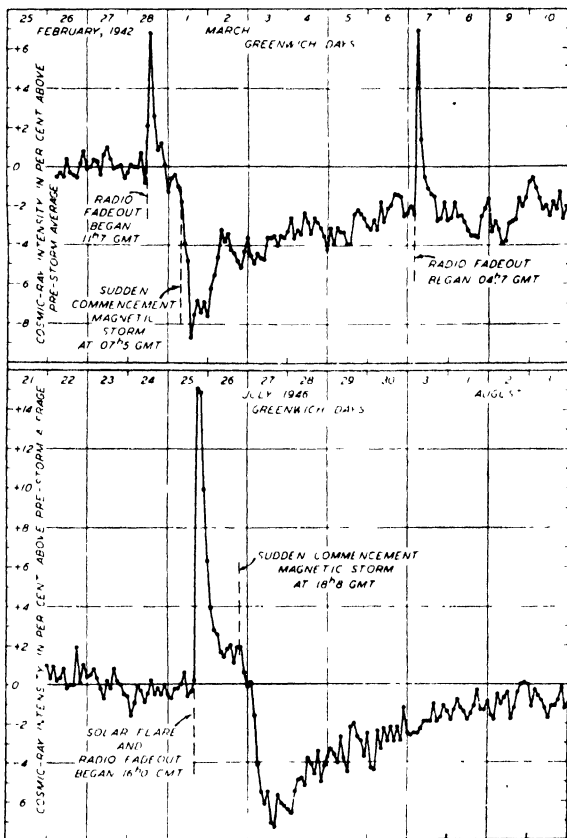


FIG. 2. Three striking increases in cosmic-ray intensity observed shortly after commencement of violent solar flares and radio fade-outs. The origin of cosmic rays is a great puzzle, but this discovery indicates that some particles may be accelerated to cosmic-ray energies by great disturbances at or near the surface of the sun. If this is true, the same thing may occur on myriads of other stars.

ing lesser solar flares, perhaps too slight to be observed because of limitations of existing recording instruments? As a step toward obtaining an answer to this ques-

tion, a detailed study has been made to determine requirements for coincidence counters and large ionization chambers with sufficient sensitivity and low statistical fluctuation to show the fine structure of cosmic-ray activity without ambiguities arising from the production of "bursts" due to nuclear processes produced by cosmic rays when they strike our atmosphere or materials near the recording instruments. Assembly of a very large cosmic-ray ionization chamber for this purpose is progressing.

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ANALYSIS

Extensive new descriptions of the earth's main field and its secular change, 1905-1945, mainly in more accurately mapped form, were unsuccessfully compared with those of other geophysical phenomena manifested in the crust. There were, however, aspects of these comparisons that seem worthy of further examination. For example, there seems to be some correlation of secular change with general features of the stress distributions within the earth's crust, deduced by Vening-Meinesz in his attempt to explain faulting and topography of the earth's surface, again in turn related to other crustal phenomena. Examination of this possibility is being continued.

A spherical harmonic analysis of the earth's main field for 1945.0 was begun and completed during the present report year, analogous to that carried out previously for secular change. This analysis of carefully prepared magnetic charts indicated that the fraction of the dipole component of the main field of external origin was less than 1 per cent of the observed surface field, and thus considerably less than indicated by previous analyses. Examination of the analyses of secular change at four epochs a decade apart indicated a rather steady decrease of about 20 gammas per annum in the dipole component, though the most recent decrease, that for epoch 1942.5, is considerably less, and may indicate that the dipole component of the main field is now diminishing at a rate less rapid than during the previous century.

An external and nonpotential part of the main field, and variation of the vertical component of curl of field, postulated by the Schrödinger unitary field theory could not be detected from analysis and comparisons with the new and more accurate

descriptions of the geomagnetic field. This result is contrary to Schrödinger's findings based on Schmidt's analysis for 1885.

The new analysis gave the co-ordinates for 1945.0 of the north geomagnetic pole as $78^{\circ}.6$ N and $289^{\circ}.9$ E, and for the south geomagnetic pole as $78^{\circ}.6$ S and $109^{\circ}.9$ E; these results differ from those of Bauer for 1922 by only $0^{\circ}.1$ in latitude and $1^{\circ}.1$ in longitude.

Calculations of the main field and its secular change were completed for various levels within and beyond the earth's atmosphere, providing useful data for studies of electrical phenomena of the upper atmosphere. Vertical gradients of the main field and its secular change were calculated for the earth's surface, but attempts to correlate these with other geophysical phenomena were unsuccessful.

Current functions which could produce the main field and secular change calculated for flow of currents on a thin spherical shell at depth 3000 km were found to be highly complex. This renders it unlikely that a major part of the main field or secular change could originate below the surface of the earth's central core, though it might be admissible to postulate flow of current very near the surface of this core, as suggested recently by Elsasser.

H. W. Babcock, of Mount Wilson Observatory, has recently made the epoch-making discovery that various rapidly rotating distant stars have intense magnetic fields. This result is of the highest interest in relation to the origin of the earth's main field, and immediately focuses attention on electric-current hypotheses such as that of Elsasser. A theoretical investigation is accordingly being directed toward discovering the effect of rotation of a body upon internal fluid motions which could generate the geomagnetic field, as well as those of astronomical bodies. Not unrelated to this

problem is our current analytical attempt to check by actual calculation the possibility that the increase in cosmic rays during solar flares may be ascribed to changes in the solar magnetic field.

The unexplained average augmentation in earth currents during January, as compared with December and February, found by Rooney for Tucson has likewise been found in 12-year means for the solar daily magnetic variation at stations throughout the western hemisphere, but not in the eastern hemisphere.

One of the volumes based on the observatory and survey program, entitled *Description of the earth's main magnetic*

field and its secular change, 1905-1945, prepared by Vestine and coworkers, was published. This volume summarizes in more accurate mapped form the principal descriptive results and statistics of the extensive magnetic surveys carried out on land and sea by the Department and its collaborators. A forthcoming volume, *The geomagnetic field, its description and analysis*, summarizes new and extensive results of magnetic observatories throughout the world, and includes results of detailed analysis of the main field and its secular change and studies of geomagnetic fluctuations.

LABORATORY PHYSICS AND BIOPHYSICS

FERROMAGNETIC STRUCTURE

One of the remaining puzzles in the behavior of ferromagnetic materials is the exact size of the smallest volume of ferromagnetic material which has an intrinsic saturation. It has been understood for a long time that such small saturated volumes or "domains" were necessary to explain magnetization curves. It was the partial understanding of the effect of such microscopic volumes on microscopic behavior that led to the development of such widely differing magnetic materials as Permalloy and Alnico 5. Yet much of our knowledge concerning the character of domains has remained of empirical and engineering nature.

In December 1946, Dr. Charles Fittel, of the Research Laboratory of Electronics at the Massachusetts Institute of Technology, proposed a theory for the structure of ferromagnetic domains which was susceptible of experimental verification for very thin films. This theory was important because it gave quantitative reasons for expecting that the size and geometry of domains are not invariant, as had usually

been supposed, but depend in a very specific way on the dimensions, crystal structure, and other anisotropic energies of the material. This made reasonable the wide range of apparent domain sizes observed by various methods, which gave domain sizes with linear dimensions ranging from 5×10^{-5} cm, indicated by the scattering of polarized neutrons in iron, to about 10^{-8} cm, from measurements of Barkhausen effect and powder patterns. Kittel's theory predicted that a very thin film 10^{-5} cm thick or less would be a single domain infinite in extent in the other two directions.

In co-operation with the Naval Ordnance Laboratory, preliminary measurements were made on very thin films of iron, the Naval Ordnance Laboratory making the thin films and the Department making the necessary magnetic measurements, which were possible with the extremely sensitive apparatus used to measure the magnetization of clays. It was found that such very thin films were in fact single domains saturated at about 16,000 gauss, and that this value of satura-

tion was independent of film thickness. Although no exact magnetization curve has yet been obtained because of the difficulties encountered in dealing with such minute amounts of material, the evidence indicates that such films have a rectangular magnetization curve in which the film actually always remains saturated, but in which the direction of magnetization can be rotated fairly easily through 360° . In other words, the film can be magnetized in any direction in its plane, but it cannot be demagnetized in the way that is possible for a normal magnetic material. The results of this investigation are still preliminary, but there appears to be little doubt of the behavior described above. Thus, Kittel's calculations, together with this experimental verification, provide a considerable quantitative advance in the understanding of the behavior of ferromagnetism.

NUCLEAR PHYSICS

The two electrostatic generators of the Department have been used during the past year primarily for measurements on the angular distribution of protons and alpha particles emitted in the disintegration of several of the lighter elements. One may hope to learn something of the nature of the nuclear-energy levels involved in a disintegration from a study of the angular distribution of the emitted particles, if a situation can be found where the energy levels are not too high above the ground level of the nucleus. This is because the energy-level density increases with increasing excitation energy, hence the effect of neighboring levels becomes important.

The first postwar effort was put into getting the one-million-volt generator back into operation. A voltage-stabilizing system was installed to improve the performance of the machine. Angular distri-

bution measurements were undertaken on the two proton groups occurring in the disintegration of oxygen by deuterons. This is an interesting reaction for study, since O^{16} (oxygen of mass 17) is supposed to have a closed-shell arrangement of neutrons and protons; an addition of a neutron to form O^{17} would then start a new shell. Also, both an excited energy level, 850 kilovolts above the ground level, and the ground energy level of O^{17} are involved. With the emission of the shorter-range protons O^{17} is left in the excited energy level, and with the emission of the long-range group it is left in its normal ground level. The results with deuterons of bombarding energies up to 1.15 million volts indicated that the long-range proton group had a greater yield in the forward direction with respect to the incident beam, whereas the short-range group had a greater yield in the backward direction. In the spring of 1947 the large pressure electrostatic generator was again put into operation. With this, protons and deuterons up to 3.2 million volts were made available, and the above series of measurements were extended to 3.2 million volts. It was found that the angular distributions varied considerably with energy above 1.5 million volts. A marked change occurred in the energy region around 1.8 million volts, where a competing reaction sets in, in which neutrons are emitted. Dr. David Inglis, of Johns Hopkins University, who has assisted with these experiments, has been working on the theoretical analysis of the oxygen data. How far present nuclear theory can go in explaining the rather complex changes which occur in this reaction is still uncertain.

The angular distribution of the alpha particles emitted in the reaction of protons bombarding lithium of mass 7 has been studied. This reaction had been investigated with proton energies up to 1.4 mil-

lion volts by several other research groups, who found the angular distribution to obey a rather simple law with the yield of alpha particles equal to $1 + A(E)\cos^2\theta$, where θ is the angle the alpha particle makes with the incident beam of protons (in the center of mass co-ordinate system) and the coefficient $A(E)$ is a function of energy of the bombarding protons. $A(E)$ was found to reach a maximum at about 1 million volts. We have extended these measurements to 3 million volts and have found that above 1 million volts an additional term $B(E)\cos^4\theta$ is needed to fit the data. Also the value of $A(E)$ continues to decrease with increasing E .

Preliminary observations with deuterons bombarding lithium of mass 6 disintegrating to two alpha particles give a distribution above 0.75 million volts also of the form $1 + A(E)\cos^2\theta$. Whether $A(E)$ again has a maximum value has not yet been determined.

A series of interesting observations was made during the year on the splitting of the deuteron when it encounters a target. A beam of 15 MEV deuterons from the cyclotron gives rise to a marked emission of high-speed neutrons in the forward direction when it strikes a target of copper, and this effect is enhanced with a target of aluminum. With carbon, on the other hand, the neutrons are still emitted in the direction of their original velocity as deuterons, but energy loss is evident.

BIOPHYSICS

With the production of isotopes, both stable and radioactive, biology and general physiology have a new approach to many of their unsolved problems. The technique and the philosophy implied by these new physical tools necessitate a knowledge of and respect for two sets of training—that of the physicist and that of the biologist—

before a good biophysical approach can be made. The accuracy of measurement and the micro-quantities capable of use both lead to new forms of instrumentation and permit a deeper probing of the life processes than was possible heretofore. The selection of the problems and of the particular animals or plants to be used has to be based on a wide knowledge of general biology. Living processes up to now have not attracted the attention of men trained in the physical sciences to any large degree.

Provision was made for an approach to such studies just before the war by the construction of the cyclotron at the Department of Terrestrial Magnetism. With this tool it is possible to produce the radioactive materials necessary for such investigations. During the war the cyclotron was intensively used for a series of medical experiments and tests with heavy metal tracers carried out in collaboration with the Navy. The knowledge and experience gained in nuclear physics work at the Department can be well utilized in the field of biophysics. The fundamental part played in the life process by light, both in plant and in animal, is another phase of biophysics which has reached the stage of experimentation that calls for techniques of a physical nature. With these facts in mind, a modest biophysical program has been started with the co-operation of biologists in other institutions. The radioactive tracer technique has been the basis of the first series of experiments directed toward problems of general interest in physiology. The cyclotron has also been extensively used for the production of radioactive isotope samples, contributed to many biological and medical groups in the United States and in half a dozen foreign countries.

Passage of minerals from mother to embryo. In co-operation with the Department of Embryology of the Carnegie Insti-

tution and with the Johns Hopkins Hospital, radioactive sodium (Na^{24}) was followed across the placental membrane to the embryo from the 10th week of pregnancy to term. The rate of placental transfer at various times in normal pregnancies has been followed by this technique, and it has been shown that the permeability of these tissues increases about 70 times during the period of gestation. Several modifications due to disease were also followed. The fetus at the 12th week receives 160 times as much sodium as the growing tissues require, and by the 40th week it is receiving 1100 times as much as is required.

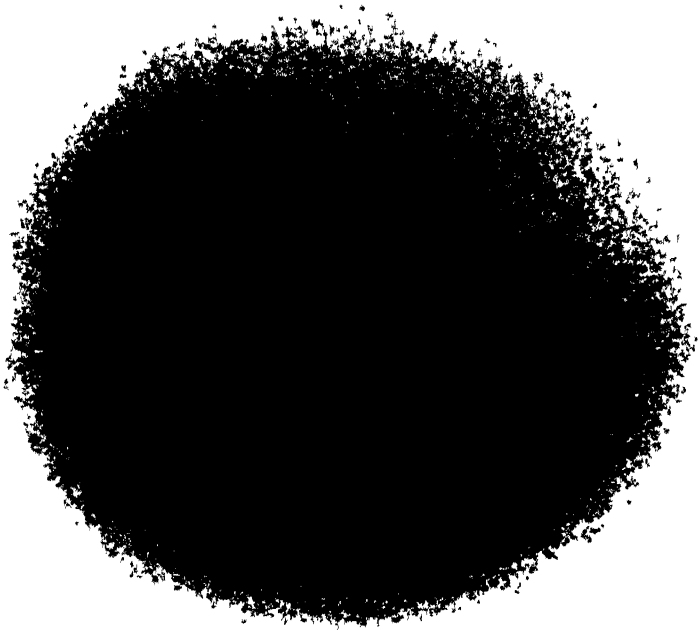
The origin of iron in the fetus. Previously two views have been developed of the origin of fetal iron: (1) that it comes from the hemoglobin of the maternal red cells which are destroyed by the placenta; (2) that it is derived from the iron in the plasma which is put there from the iron stores of the liver of the mother. By tagging red cells with radioactive iron in an animal and then transfusing these red cells into the pregnant animal, the radioactive iron can be followed into the fetus. In a similar manner the plasma iron can be tagged in an animal and this material transfused into a pregnant animal. These studies are now under way and new methods of iron determination have been developed. In a similar manner the permeability of the placental membranes to chlorides is under study.

The rate of exchange of minerals in the aqueous humor and lens of the eye. In co-operation with the Department of Embryology of the Institution at Baltimore, the rate of exchange of radioactive sodium (Na^{24}) between the plasma and aqueous humor of the eye and that between the aqueous humor and the crystalline lens were studied. The radioactive sodium was injected intravenously, and after a definite

period of time the aqueous humor and the crystalline lens were removed. These studies have established that the steady-state ratio of plasma sodium to aqueous-humor sodium is 0.920 in the guinea pig. Because of the difficulties of studying the metabolism of the eye and its various parts, there has been, up to the present, very little research in the physiology of this organ. The tracer technique permits a new approach to this topic.

Permeability and rate of exchange of sodium in the ovarian eggs of the frog. The single-cell nature of the egg and its huge potentialities of development into a complete animal have caused it to be the center of much investigation. Little is known of its complex relations with its external environment, and still less as to its internal specialization. In this study we have examined closely the permeability and the rates of diffusion in a specific cell, the ovarian egg in both the living and the dead condition. Quantitative differences in the diffusion of sodium into live and dead eggs have been studied. When dead eggs are used, all the sodium is exchanged; that is, the percentage of tracer sodium in the eggs after standing in Ringer solution containing these atoms is the same as the sodium content of the solution. Half of this exchange occurs in about 5 minutes. Calculations for diffusion into a sphere the size of the egg show that the time of half exchange should be about 5 minutes. The dead egg acts like a sphere of Ringer solution, and the egg membrane forms practically no barrier.

This behavior must be contrasted with the conditions found in the living egg. At the end of 4 hours only 10 per cent of the sodium in the egg has exchanged, and nearly all this exchange occurs in the first half-hour. Evidence from radio-autographs shows that the Na^{24} is distributed throughout the whole egg as early as 30 minutes



Photographic imprint made by radioactive sodium diffusing into nucleus of frog's egg. Sodium is shown to be admitted or excluded by change in calcium concentration surrounding egg. This print is made from thin frozen egg after exposure of 6 minutes to solution containing radioactive sodium.

after the start of the exposure. Thus only 10 per cent of the sodium in a live egg is freely exchangeable, and half of this is exchanged in about 15 minutes. This means that the outer membranes do not greatly slow down diffusion of sodium into the egg. It was demonstrated that the diffusion of Na^{24} into the eggs is essentially a reversible process for short-time exposures, but exposures up to 19 hours gave evidence of more exchange after some hours. This may not be reversible.

Calcium excess or deficiency in the ambient Ringer solution does not affect the initial rate or amount of exchange of Na^{24} . After several hours a difference becomes apparent: a deficiency of calcium renders more of the sodium in the egg exchangeable, a fact which may possibly indicate that some membranes belonging to an inner structure of the cell have become more permeable.

Radio-autographs of single egg cells. Radio-autographs of egg cells showed definite rates of diffusion and localization of Na^{24} . The striking feature was that Na^{24} was concentrated in the nucleus. An estimate of the density of blackening of the film shows that the nucleus contained about twice as much Na^{24} per unit volume as the cytoplasm. Hence the nuclear membrane is readily permeable to sodium, and the amount of sodium available for exchange is relatively greater in the nucleus than in cytoplasm. Distribution of sodium throughout the remainder of the egg appeared to be relatively uniform, though our technique was not sufficiently refined to detect local variations. The diffusion rate of the mobile sodium in the egg is close to that in water. The diffusion of sodium into the nucleus is influenced by excess or deficiency of calcium in the surrounding Ringer solution.

The physiology of the blood-forming tissues. The aim of this project is to de-

termine in which cells antibodies are formed. When a foreign protein is introduced parenterally into an animal, gamma globulins are produced after a variable period of time which react specifically with the antigenic protein. Reactions then result in precipitation, agglutination, detoxification, etc., of the antigenic protein.

The early work in this field seemed to indicate that the cells which produced the antibodies were the cells of the reticulo-endothelial system. More recently, antibodies have been shown to be present in high concentration in lymphocytes. At the National Institute of Health, Habel and Endicott have studied the problem with rabies virus in mice and have shown that mice given 400 r whole-body X-radiation lose their ability to become immune to rabies for a period of time which corresponds to the time required for the lymphoid tissue to regenerate. During this time there is no demonstrable damage to the reticuloendothelial cells.

In co-operation with Dr. Endicott and his group we have established the techniques necessary for antigen-antibody studies using tagged antigens produced *in vivo* with the choice of proper animals and controls as well as the development of chemical and biological procedures. Two experiments have been carried out with rather striking results.

Studies in Guatemala. The objects of this study in collaboration with the Pan American Sanitary Bureau and the United States Public Health Service were as follows: (a) to determine to what extent antimony administered as tartar emetic localizes in the nodules and adult filarids of onchocercosis, using tartar emetic containing radioactive antimony; (b) to determine the effect of BAL on the excretion of a single dose of antimony in this form; (c) to accumulate further data on the distribution in the human body and excretion of

antimony administered in this form, with especial reference to the blood and urine.

As a result of these studies it was found that BAL did not affect the elimination of the antimony compounds when used under our special dosing schedule. The adult filarids in this study showed very high specific uptake of the antimony, and the nodule containing the filarids also showed some concentration of the antimony over the surrounding subcutaneous tissues used as a control medium.

Pharmacology of heavy metals with specific application to tropical diseases. Thus far we have shown that regardless of the location of the adult filarid (thoracic cavity, heart, or subcutaneous tissues), there has been a specific uptake of antimony and arsenic by the adult parasite. These results have been found in man, dog, hamster, and cotton rat. Concentration of these elements has also been found in the thyroid, parathyroid, and liver. After single or multiple administration of these elements the concentration in the blood has always been low. In fact, 24 hours after dosage the blood level is usually the lowest concentration found in the entire body. The white rat, however, has reacted anomalously to trivalent compounds of antimony and arsenic, the blood level 24 hours after dosage being 100 times greater than that found in any other animal. Studies are under way now to determine the nature of this difference.

An improved method of tracer micrography. Conventional methods of radioautograph technique are limited by lack of resolution associated with film grain size. In collaboration with L. Marton, of the National Bureau of Standards, a start has been made toward removing this limitation. The method employed uses an electron optical lens system to obtain a magnified image of the radioactive source.

Cyclotron operation. During the report

period the cyclotron was in very active use for both the laboratory physics and the biophysics program. Work on a number of projects was facilitated when an outside beam was obtained. The sale of radioactive isotopes by the Atomic Energy Commission has had a double effect on requests for cyclotron-produced materials. Some of the demand for the isotopes which can be produced by the "pile" has been relieved, but additional interest has been stimulated in tracer studies. It appears that the nuclear reactor cannot produce in high specific concentrations such isotopes as Be⁷, C¹¹, F¹⁸, Na²², Mn⁵³, Co⁵⁷, Cu⁶⁴, Zn⁶⁵, As⁷³. Hence the cyclotron is assured of continued usefulness in preparing tracer substances.

Shipments of radioactive material produced by our cyclotron were made to numerous research groups in the United States and to New Zealand, Sweden, Denmark, France, Australia, South Africa, Great Britain, and Canada.

Long-range biophysics program. To date biophysics has little recognized standing as a separate scientific discipline. Nevertheless, there is a widespread conviction that the processes in living matter involve important physical phenomena. How can physics best make its contributions to answering crucial questions concerning living matter? To date this question has not been answered. The efforts of our group of several physicists interested in biological problems will be directed during the next several years toward the formulation of questions in this field which can be regarded as fundamental to living systems and yet can be made accessible to attack and observation in terms of physical processes. Most of the present specific problems lie squarely across the three fields of physics, chemistry, and biology. Close collaboration with certain workers in each field is necessary and planned.

OPERATIONS AND STAFF

CO-OPERATIVE WORK OF THE DEPARTMENT

In accordance with its general practice of advancing projects through collaboration with other individuals and organizations, the Department has contributed to many co-operative investigations.

In the field of geophysics the Department collaborated with the Air Weather Service in a project designed to ascertain whether thunderstorms supply negative electricity to the earth at a rate which would account for the electric field observed in all typical fair-weather areas. Volcanological investigations were carried out at Umnak Bay in co-operation with the United States Geological Survey.

In order to assist in supplying necessary magnetic data at sea, of which the world's hydrographic offices stand in need, the Department prepared and forwarded detailed plans of the *Carnegie* to the USSR for use in planning a proposed nonmagnetic vessel.

Three sets of cosmic-ray plates were sent to Peru in February 1947 for exposure at different altitudes to test the variation of frequency of cosmic-ray bursts with altitude. This experiment was undertaken in co-operation with the University of Virginia.

Co-operative plans were made for work with Professor Amaldi, of the University of Rome, who visited the Department for a period of two and a half weeks for concentrated technical discussion.

In the field of biophysics, we have co-operated in a wide variety of ways. A month was spent by one of our investigators in Guatemala in connection with filariasis studies in co-operation with the Pan American Sanitary Bureau and the United States Public Health Service. Radioactive materials have been supplied to many institutions throughout the world

for use in researches pertaining to biology and medicine.

Much use has been made of data obtained at our observatories in Huancayo and Watheroo, in connection with geophysical and ionospheric studies. Dr. D. F. Martyn, of Commonwealth Observatory, Mount Stromlo, Canberra, Australia, has used Huancayo data exclusively in the preparation of an article on "Lunar tidal variations in the F-region near the magnetic equator," and Dr. O. Burkard, Institut für Meteorologie und Geophysik, University of Graz, requested ionospheric data from Huancayo for use in his investigations of the question regarding the nature of measured radiation.

A research and development task-order contract was negotiated with the Office of Naval Research on January 1, 1947, for co-operative work with the Navy on the deeper layers of the earth's crust by observations on seismic waves produced by artificial explosions.

THEORETICAL PHYSICS CONFERENCE

The Ninth Washington Conference on Theoretical Physics was held in Washington, D. C., October 31 to November 2, 1946, under the joint auspices of the George Washington University and the Carnegie Institution of Washington. The subject of discussion was "The Physics of Living Matter," and a group of investigators in biology and in theoretical physics joined in a series of informal meetings for discussion of the border line between biology and physics. This conference is a continuation of annual meetings which were interrupted by the war. It was attended by representatives of twenty-four universities, research organizations, and government bureaus. The principal purpose of

the conference was to interest and instruct the theoretical physicists with regard to a group of special problems on the frontier of biology.

ADMINISTRATION AND OPERATION

The main laboratory of the Department was repainted during the year, and new ceilings were installed in about half the rooms. Furthermore, as a symbol of the shift of emphasis toward new problems and activities, and to insure orderly handling of the older records and research material, each member of the staff was shifted to a new room or laboratory early in the year to start on his new projects, and all valuable materials connected with past activities were transferred to a special archives space in the attic.

The Standardizing Magnetic Observatory was reroofed, and the interior was changed to make it more suitable for laboratory investigations.

The remaining work on all war contracts still in effect on July 1, 1946, consisting largely of final reports and preparation of accounts, was terminated early in the report year except for one contract with the Bureau of Ordnance, Navy Department, which is delayed only for a final bill for publication of a completed volume of maps and data. Final payments have been received except for two war contracts.

The construction of the main building of the Derwood Experimental Laboratory was resumed in April and was practically complete at the end of the report year.

The Department continued its support of the *Journal of Terrestrial Magnetism and Atmospheric Electricity* under the editorship of Dr. John A. Fleming, retired Director of the Department.

The Department was fortunate in having a number of outstanding guest investigators attached to the staff for varying periods. These are named in the appended list, which shows also the regular members of the staff, most of whom were employed for the entire report year.

The American Geophysical Union, which occupied office space in our main laboratory for a number of years, moved during the winter to more desirable quarters at the Administration Building of the Carnegie Institution, 1530 P Street, Northwest.

LECTURES GIVEN BY NONMEMBERS OF DEPARTMENT

November 1946, two lectures were given by E. Amaldi, and one by Marcel Schein on cosmic rays.

April 2, 1947, "Terrestrial magnetism and the earth's core," by Walter M. Elsasser.

April 7, 1947, "Wartime development of physics in Holland," by H. B. G. Casimir.

April 9, 1947, "Physical basis of the domain theory of ferromagnetism (with application to the magnetic properties of thin films and small particles)," by Charles Kittel.

May 9, 1947, "Investigation of cosmic rays by means of rockets," by Marcel Schein.

May 19, 1947, "The origin of the universe," by E. Teller.

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STAFF AND ORGANIZATION

SCIENTIFIC STAFF

- Geophysics*: L. V. Berkner, S. E. Forbush, O. H. Gish, R. W. Goranson (from Geophysical Laboratory), E. A. Johnson, W. J. Rooney, S. L. Seaton,* K. L. Sherman,* O. W. Torseson, M. A. Tuve, E. H. Vestine, G. R. Wait, H. W. Wells.
- Laboratory and Biophysics*: P. H. Abelson, D. B. Cowie, N. P. Heydenburg, R. B. Roberts, M. A. Tuve.
- Guests, Associates, and Visiting Investigators*: A. P. Bondarenko, Kiev Institute of Geology,

Ukraine; C. Y. Chao, National Central University, Nanking, China; C. L. Critchfield, George Washington University; W. R. Duryee, National Institute of Health; J. W. Graham, Johns Hopkins University; C. M. Hudson, Office of Chief Ordnance, War Department; D. R. Inglis, Johns Hopkins University; T. Murphy, University College, Dublin, Eire; A. T. Ness, U. S. Public Health Service; T. H. Pi, National Central University, Nanking, China; Miss J. Roquet, Institut de Physique du Globe, University of Paris; J. E. Sreb, Applied Physics Laboratory, Johns Hopkins University; D. Whitehead, University of Virginia.

* Resigned.

OPERATING STAFF

Administrative: M. B. Smith, W. F. Steiner.

Office and Clerical: J. J. Capello, Miss R. C. Dermody, W. N. Dove, H. D. Harradon, W. C. Hendrix, P. L. Moats, Miss H. Russell, A. D. Singer.

Instrument Shop: B. J. Haase, L. A. Horton, J. G. Lorz, F. B. Thomas.*

Laboratory Assistants and Technicians: S. J. Buynitzky, J. B. Doak, E. H. Fogel,* P. A. Johnson, C. J. Ksanda, C. A. Little, Jr.

Maintenance: C. Balsam, C. W. Burger, H. W. Hackley,* S. W. Malvin, E. Quade.

Observatory Work and Computers:

Office: Miss E. Balsam, F. J. Chernosky,*
Miss I. Lange, W. C. Parkinson, W. E. Scott.

* Resigned.

Huancayo Observatory: T. Astete, M. Casaverde, A. A. Giesecke, Jr., M. W. Jones,* H. Koller, P. G. Ledig, E. Melgar, W. D. Parkinson.

Watheroo Observatory: A. Bevis, R. J. Erskine, G. R. Feirclough, S. B. Hudson, H. Layton, A. E. McCall, D. L. Overheu, A. Parkes, L. P. Tulley, F. W. Wood.

Part-Time and Temporary Employees: There were 42 part-time and temporary employees engaged during the year, usually for short periods, whose work was concerned largely with the completion of war-contract and publication work. Miss M. Walburn, production assistant, was assigned by the Office of Publications to publication work at the Department for the entire report year.

* Resigned.

SPECIAL PROJECTS: TERRESTRIAL SCIENCES

FRANK T. GUCKER, JR., Northwestern University, Evanston, Illinois. *Studies on specific heats of aqueous solutions.*

A strong electrolyte dissolved in water causes a contraction in volume, which indicates a compression of the water molecules around the ions. Simultaneously, the heat capacity of the solution is reduced below that of water. In fact, the apparent molal heat capacity of the salt is often negative, showing that the heat capacity of the solution is less than that of the water it contains. The apparent molal heat capacity in dilute solutions is known to increase linearly with the square root of the molality, as predicted by the Debye-Hückel theory, and this relation often holds within 0.01 per cent in the specific heats, up to concentrations of 1 or 2 *m*. The Debye-Hückel theory does not predict the value of the apparent molal heat capacity at infinite dilution, but Zwicky has attempted to do so on the basis of the electrostriction of the water, the heat capacity of which is known to be decreased by pressure, at room temperature. However, on the basis of Bridgman's P-V-T data for water, Zwicky calculated that pressure should increase the heat capacity of water at temperatures above about 65° C., and predicted a similar increase for the specific heats of aqueous solutions of strong electrolytes. The present research was carried out to test this theory and obtain some precise specific heat measurements in a range where none existed.

Dr. Frank W. Lamb used the differential calorimeter with variable heaters developed in this laboratory, and modified it to obtain precise results up to 85° C. He

determined the specific heats of solutions of potassium chloride, sodium chloride, and sodium bromide from about 0.1 *m* to near saturation, at 20° intervals from 5 to 85° C. The results were similar for all these salts. The apparent molal heat capacities plotted against the square root of the molality increase most rapidly at low temperatures, where the curves are definitely of sigmoid shape, with a maximum slope near the middle. At higher temperatures they all are flatter. The apparent molal heat capacities at infinite dilution increase rapidly from 5 to 25° C., but pass through a maximum at about 60° and actually decrease to 85°. For concentrated solutions, the curves are flatter and the maximum occurs at a lower temperature. These results indicate a discrepancy either in the P-V-T data for water or else in Zwicky's theory correlating electrostriction and specific heat. Further experimental and theoretical work is desirable along these lines, as well as an extension of the experimental study of specific heat of aqueous solutions to temperatures as near the critical as possible, which will be undertaken under this project.

Our present results allow a calculation of the standard entropies of these salts in aqueous solution, over the range of temperature we covered, from the values given by Latimer, Pitzer, and Smith at 25° C. There is a surprisingly large decrease in standard entropy between 5 and 85° C., nearly the same for all three salts, and averaging 17 per cent.

ing these phenomena, but rather must become the *primum mobile* to fashion man's evolution.

In the contemplation of this vexed problem, which is so fraught with tremendous consequences, the occupation with various aspects of the evolution of living beings exerts an influence for both humility and skepticism. The concept of a homocentric world, dominated by the will of man, or, perhaps more properly, by the will of a few men, becomes a crumbling doctrine. That something of the nature of evolution has occurred, the great mass of scientific evidence gives ground for belief. But for the vastly more significant question as to how these changes occur, what causes bring them about and what mechanism is involved—for the solution of these problems we are only at the threshold of knowledge.

The race of man is as the race of leaves:
Of leaves, one generation by the wind
Is scatter'd on the earth; another soon
In spring's luxuriant verdure bursts to light.
So with our race; these flourish, those decay.

* * *

The first development of chlorophyll in the illuminated leaf is one of the most remarkable phenomena in the plant world. This greening process makes the plant a self-sufficient organism, capable of manufacturing food by photosynthesis. The detailed chemical steps involved in the process of chlorophyll formation are not yet fully understood, but some of them have now been more clearly elucidated. It has been possible to differentiate several steps in the intricate chemical reactions which lead to the formation of the complex chlorophyll molecule. Some of these steps are accomplished by means of light, others are purely thermal processes, probably effected by special enzymes. It has been possible to follow separately the course of these two types of action by determining

certain components of the leaf when this is maintained at different temperatures. This is made possible by the fact that purely photochemical reactions are influenced but slightly by changes in temperature, whereas ordinary chemical reactions obey rather definite laws in regard to the influence of temperature on their rates. From these studies is evolving a concept of a series of integrated photochemical and thermochemical reactions through which simple inorganic and organic substances are elaborated into the highly complex molecule of chlorophyll.

In the course of their evolutionary development plants have taken on an enormous diversity in form and structure. It has been one object of systematics and taxonomy to discover order amid this diversity. By comparative study of the structures of plants it has been possible to trace the development of groups of organisms and to learn something of their present status in relation to their early progenitors. While through their evolution plants have taken on this marked diversity in structure, in habit of life, and, to a considerable extent, also in function, in respect to their means of food manufacture they appear to have undergone little change. This conclusion, the result of an extensive study covering a wide variety of plants, is based upon the observation that chloroplast pigments, which are an essential part of the photosynthetic apparatus of all plants, have varied little with the evolution of the species of each major taxonomic group. Even in the evolution of the main taxonomic groups of plants, the variation of these pigments has not been great. Only minor variations of the chlorophyll and carotene pigments have been observed, accompanied by somewhat greater variations of the xanthophyll pigments. It would appear, therefore, that whereas in many respects the plant has adapted itself to

changed conditions and has modified its form and habit of life, the fundamental process of photosynthesis seems always to have required the same extraordinary delicate apparatus.

Another aspect of this apparent rigidity of the synthesizing apparatus of the plant may be illustrated by the results obtained from culture of a unicellular alga, *Chlorella*, under a wide range of environmental conditions. According to the culture conditions selected, the chemical composition of the plant varies enormously; under one set of conditions it will produce, for example, 5 per cent of fat, and under another set of conditions 85 per cent. In the first case the cells maintain a high content of chlorophyll and appear dark green. In the second case, with high fat production, the cells carry on their synthesizing work with about one-thousandth the quantity of chlorophyll found in the former and are a yellow-green. The nature of the chlorophyll pigments in the two cases is the same; qualitatively the synthesizing apparatus appears to be a rigid one. The amounts of the pigments, however, vary tremendously in the two cases, so that quantitatively the system appears to be very flexible, and this flexibility apparently is also reflected in the chemical nature of the products which accumulate.

Nearly 300 interspecific hybrids, representing 35 combinations, have now been produced in the grass-breeding program which this Division has undertaken in co-operation with the Soil Conservation Service of the United States Department of Agriculture. Many of these hybrids and their offspring are now under test in the field stations of the Institution and in the nurseries of the Soil Conservation Service. The test plantings at Pullman, Washington, and other field stations give promise that some of the new grasses will prove valuable, because they combine a very

favorable form and yield with disease resistance and extension of activity into the dry summer. As was expected, some of the hybrids are more successful in one location than in another. Grasses of the proper heredity must be selected for each major climatic region, and there is now the possibility of a wide selection from the combinations which have already been made.

These hybrids, of the genus *Poa* or bluegrasses, have been obtained by crossing distantly related species originating from very unlike environments. These species and many of their hybrids produce the bulk of their seed by asexual means, and, accordingly, breed true. The purpose of this program was to explore the crossability and the inheritance of species that produce most of their seed in this manner. One of the most promising grasses combines the heredities of a giant bunch grass from eastern Washington and a subarctic race of the sod-forming Kentucky bluegrass from Swedish Lapland north of the Arctic Circle. Another high-quality grass that promises to provide much-needed summer grazing in the latitude of Pullman, Washington, is a hybrid between the same giant bunch grass and a race of Canada bluegrass from the Mediterranean slopes of Asia Minor. For California Coast Range conditions hybrids are now under test that combine the California bluegrass, which is a tufted type, and various races of Kentucky bluegrass. These hybrids are superior to the native Poas in this region, because they have a considerably more extended period of summer activity.

The grass-breeding program has demonstrated that hybrids can be produced between such distantly related and unlike parents having the asexual reproductive mechanism. It has also shown that only about one-third of the hybrids reproduce asexually like their parents, and that the

remainder are sexual. The latter, however, segregate some very promising offspring, part of which, in turn, may reproduce asexually. This question is being explored further, and it offers possibilities of selecting out many new grasses unlike anything produced hitherto.

The scientific contribution of this program is now outweighing the practical aspects, which have pointed the way to what can be done in improving plants of agronomic importance that follow this specialized method of seed formation.

BIOCHEMICAL INVESTIGATIONS

H. A. SPOEHR, J. H. C. SMITH, H. H. STRAIN, AND H. W. MILNER

CHLOROPHYLL FORMATION IN ETIOLATED LEAVES

The investigations on the chemistry of chlorophyll formation (Year Book No. 45, p. 104) have been extended by Dr. Smith to include analysis of the process at different temperatures. By following the development of greening in etiolated leaves under these conditions, some differentiation can be made between the reactions which are dependent on light and those which are not. The results show that chlorophyll formation is a combination of pure photochemical reactions and thermochemical reactions, which are integrated in a complicated manner.

Protochlorophyll. Seedlings germinated and grown in the dark possess a small quantity of yellow-green pigment known as protochlorophyll. For many years it has been known that when such seedlings are illuminated, this pigment disappears and chlorophyll is formed concomitantly. Because of the concurrence of the disappearance of one pigment and the formation of the other, it has been assumed that protochlorophyll is the direct precursor of chlorophyll, the change being the result of a photochemical action. Similarities in the chemical structure of the two pigments have strengthened this assumption, though no adequate proof of this relationship has been produced.

Experiments performed during the past year have yielded some information con-

cerning the role of protochlorophyll in chlorophyll formation. Only a limited amount of chlorophyll is produced by illumination of etiolated barley seedlings at low temperatures, 0° C. This fact argues for the existence of a limited quantity of preformed precursor in the seedlings at the time when illumination is begun. During the period of illumination that is required for maximum chlorophyll formation at 0° C., protochlorophyll disappears, and the quantity of chlorophyll is directly proportional to the amount of protochlorophyll that was present initially in the leaves. This is perhaps the most direct evidence available at present to support the theory of a physiological relationship between these two pigments.

If protochlorophyll is transformed into chlorophyll by photochemical action, no change in ether-soluble magnesium, extractable from the leaves, should result, because, on a molecular basis, protochlorophyll contains the same quantity of magnesium as does chlorophyll. It was discovered, however, that on illumination, the total ether-soluble magnesium increased to a greater extent than was required by the chlorophyll formed, in spite of the disappearance of the protochlorophyll. The determination of the constitution of this new ether-soluble magnesium compound remains a problem for future investigation.

Because protochlorophyll is destroyed by illumination, it must be regenerated in

order to account for the full production of chlorophyll, if protochlorophyll is to be regarded as the precursor of chlorophyll. Experiments have demonstrated that barley seedlings regenerate protochlorophyll when placed in the dark. Whether the rate of regeneration is sufficient to account for the rate of chlorophyll formation remains to be determined.

Chlorophyll a the first chlorophyll formed. Analysis of the chlorophyll produced by illuminating barley seedlings at $0^{\circ}\text{C}.$, after they had been grown in the dark, showed the presence of only chlorophyll *a*. The absorption spectrum of the original ether extracts as well as chromatographic adsorption analysis demonstrated that if chlorophyll *b* was formed at all, it was present only in an exceedingly small amount. These results corroborate the conclusions from other workers' experiments performed under different conditions, and strengthen the general conclusion that in the early stages of greening chlorophyll *a* is formed exclusively.

Greening at different temperatures. In etiolated barley seedlings the initial stage of chlorophyll formation is a photochemical reaction, whereas the later stages are a combination of thermochemical and photochemical reactions. This is evidenced by the fact that during the first two-hour period of illumination changes of temperature affect the quantity of chlorophyll formed, and its rate of formation, very much less than during later periods.

In a leaf which has been grown in the dark and is then illuminated, chlorophyll is rapidly formed and then undergoes photochemical destruction on continued illumination at $0^{\circ}\text{C}.$ At room temperature, however, there is a continuous rapid rise in chlorophyll content up to the maximum attainable quantity. These facts indicate that synthesis and decomposition may take place concurrently. The course

of chlorophyll formation at $7^{\circ}\text{C}.$ is also in accord with this supposition. Three stages are clearly discernible: first, a rapid rise in chlorophyll content during the first two hours (photochemical reaction); second, a period of several hours in which the pigment increases slowly (largely thermochemical reaction); and third, a period of very rapid pigment increase (integrated photochemical and thermochemical reactions). The results of these experiments indicate that when constancy of chlorophyll content is attained it represents a condition of balance between destruction and synthesis of the pigment.

The effect of illumination at different temperatures on the total ether-soluble magnesium is not yet entirely clear. At $0^{\circ}\text{C}.$, the effect of light on both the formation and the destruction of ether-soluble magnesium compounds is greater than on chlorophyll itself. At $7^{\circ}\text{C}.$, the ether-soluble magnesium compounds follow much the same course as chlorophyll, but the changes are more pronounced. At $19^{\circ}\text{C}.$, the total ether-soluble magnesium increases more rapidly at first than the magnesium in chlorophyll; but in the later stages of greening at this temperature, the increases of these two nearly coincide. These facts give evidence for direct photochemical activity of the ether-soluble magnesium compounds, but are not sufficient to determine the relation between the thermochemical and the photochemical reactions.

When etiolated barley seedlings are illuminated under conditions such that different portions of the leaves are at two different temperatures, 4° and $11^{\circ}\text{C}.$, the portions at the lower temperature remain yellow, whereas the portions at the higher temperature become green. Obviously, the effect of temperature on chlorophyll formation is local.

Organic compounds of phosphorus. The

formation of ether-soluble phosphorus compounds accompanies the formation of chlorophyll. At room temperature these compounds increase very rapidly at first, but reach a nearly constant quantity in the last stages of greening. At 7° C. they behave differently from what they do at room temperature; they decrease for the first few hours of illumination, then increase rapidly, the rise corresponding to the rise in chlorophyll. At 0° C., the ether-soluble phosphorus behaves erratically, but on the whole increases. The connection between chlorophyll formation and the production of organic phosphorus compounds is obscure, but in the light of present-day concepts regarding photosynthesis and phosphorylation, it may be significant.

CHLOROPLAST PIGMENTS

It is a self-evident fact, yet one which has been insufficiently realized, that the life and survival of plants throughout their evolutionary development has depended upon the utilization of radiant energy by the chloroplast pigments. Although a great deal is known about the changes of form and habit which plants have undergone in adapting themselves to various environmental conditions on land and in the sea, little is known of the concomitant changes that may have occurred in that function which is basic to all plants, namely the process of photosynthesis. A clue to such possible changes may be obtained from a comparison of the chloroplast pigments of plants which have followed different paths of evolutionary development, in short, in representatives of widely different taxonomic groups.

Our present knowledge of chloroplast pigments is based upon investigations of relatively few plants. Moreover, these investigations have usually been restricted to

plants representing only a few taxonomic groups. In order to gain a more comprehensive understanding of the nature of the chloroplast pigments throughout the plant kingdom, several dozen additional plants, representing a wide variety of taxonomic groups, have recently been investigated by Dr. Strain. In conjunction with earlier results (Year Book No. 42, p. 79) this increased information has provided new clues to the composition, function, and evolution of the photosynthetic apparatus. Indications have been found of new relationships between particular pigments and products elaborated by photosynthesis. Suggestions have been obtained of new factors that may have determined the development of particular pigments in plants subjected to different environmental conditions. Along with fresh concepts regarding the evolution of the photosynthetic apparatus, unsuspected relationships have been revealed among plants of several taxonomic groups.

Number of pigments. About 50 chloroplast pigments have now been isolated from plants of various kinds, and there are indications that many more have yet to be described. All these pigments fall into three principal groups: (a) the green, fat-soluble chlorophylls, of which about 10 are known; (b) the yellow, fat-soluble carotenoids, usually subdivided into carotenes (hydrocarbons, with about 6 representatives) and xanthophylls (oxygen derivatives of carotenes, with some 20 or more representatives); and (c) the water-soluble phycobilins, usually subdivided into red phycoerythrins and blue phycocyanins, with a total of 4 or more representatives.

Distribution of the pigments in relation to taxonomy and evolution. All plants capable of photosynthesis contain one or two chlorophylls, one or more carotenes, and two or more xanthophylls. In some autotrophic plants, phycobilins accompany

the chlorophylls and carotenoids, but phycobilins have never been found in the absence of chlorophylls and carotenoids.

Distribution of the individual chloroplast pigments in the plant kingdom follows a definite pattern. This distribution pattern is more dependent upon the evolutionary (phylogenetic) development of the plants than upon the environment.

All the autotrophic plants, ranging from the blue-green algae to the seed plants, contain the same principal green pigment, chlorophyll *a*. Except for a small group of green algae (certain Siphonales), which contain large proportions of α -carotene, all autotrophic plants contain β -carotene as the principal carotenoid hydrocarbon. These facts may be taken to indicate that the chloroplast pigments originated from a photosynthetic apparatus common to the progenitors of the present-day plants.

From the investigations made thus far it would appear that with the evolution of some of the principal plant groups there have occurred only minor variations of the chlorophylls, but great variations of the xanthophylls and phycobilins. It is significant that certain chlorophylls (e.g., chlorophylls *c* and *d*) are restricted to a few groups of lower plants. This is also true of all the phycobilins and to a lesser degree of some of the xanthophylls, some of the latter pigments occurring in several groups. The uniformity of individual pigments within plants of each group shows that pigment composition has not varied with the evolution of the species. Variation of the pigments among plants of different groups must have occurred very early in their evolutionary development.

Most green algae, mosses, ferns, and higher plants contain the same chlorophylls (chlorophylls *a* and *b*), the same xanthophylls (lutein, neoxanthin, violaxanthin, zeaxanthin, and cryptoxanthin), and the

same carotenes (β -carotene \pm α -carotene). These facts support the view, long held by phylogeneticists, that all these organisms arose from a common ancestry. It is probable, therefore, that the chlorophycean ancestors of present-day green algae and of higher plants contained the same pigments now found in their descendants.

Fossil green algae similar to those living today have been found in geological formations believed to be several hundred million years old. It is probable that the photosynthetically active pigments of these plants have varied little, if any, in the course of these millions of years. In view of the great chemical lability of the chlorophylls and carotenoids, this constancy of the pigments in the course of countless generations that have led to the evolution of multitudes of forms is truly remarkable.

Pigments of the Siphonales. In the past year, a minor variation of the xanthophylls has been observed in the green algae of the order Siphonales. All species of this group examined thus far contain a unique xanthophyll and its ester in addition to the chlorophylls, xanthophylls, and carotenes characteristic of other green algae. Some of these species were obtained from the temperate waters near Monterey, California (through co-operation of Dr. Gilbert M. Smith and Dr. L. R. Blinks), others were collected in subtropical waters near Miami, Florida (by Dr. F. G. Walton Smith), and some were collected in the tropical waters of the Caribbean at Puerto Rico (by Dr. J. van Overbeek and Dr. H. F. Warmke). Formation of the unusual xanthophyll in the Siphonales must have occurred before evolution of the several species, which are among the oldest and most specialized of the green algae. A related group of green algae, the Siphonocladiales, obtained also in Atlantic and Pacific waters, was found not to con-

tain this uncommon xanthophyll, which, therefore, may serve as an important taxonomic character.

Chromatic adaptation and bathymetric distribution of algae. Owing to the selective absorption of red light by water, plants growing more than a few meters below the surface receive a preponderance of blue-green light. As chlorophyll has less absorption capacity for blue-green light than for red light, it is usually assumed that the presence of complementary pigments which absorb blue-green light is essential to the growth of algae in deep water. Calculations based upon the spectral absorption curves of the extracted pigments show, however, that the high concentration of chlorophyll in the chloroplasts would enable the plant to absorb a large fraction of the incident blue-green light even if complementary pigments were not present. It has, moreover, been found that green algae of the order Siphonocladiales often grow near the greatest depths inhabited by plants, about 100 meters. Yet these organisms contain the same pigments found in shallow-water green algae and in higher plants. It would appear, therefore, from this and other evidence recently collected, that our ideas of chromatic adaptation are in need of re-examination on the basis of more thorough investigation of pigment content by modern methods.

Pigments and the products of photosynthesis. Comparison of the individual chloroplast pigments with the principal structural materials and storage products synthesized by autotrophic plants has revealed that no single pigment is associated with the formation of any one principal organic substance. The great variety of organic storage products in different species of plants suggests a complex and varied reaction mechanism for the production of organic matter. The universal association

of chlorophyll *a* with oxygen production in photosynthetically active plants points to a similar reaction mechanism for oxygen liberation in all plants.

It has frequently been pointed out that *Vaucheria*, an alga of the order Siphonales, differs from other green algae in containing no chlorophyll *b* and in not forming starch. These conclusions are presumably based upon observations made on the freshwater species. It is not without interest that a brackish-water species of *Vaucheria* has been found to contain much chlorophyll *b* (about 40 per cent of the total chlorophyll), and that, after exposure to sunlight, it also contained a large amount of starch. Obviously, with respect to chlorophyll composition and to its capacity for starch formation, this species of *Vaucheria* resembles other typical green algae.

Pigments and chromatographic adsorption analysis. Experience gained through continued use of chromatographic adsorption methods for the preparation and identification of chloroplast pigments has revealed new relations between adsorbability and the molecular structure of complex carotenoid molecules. With some adsorbents such as powdered sugar, the adsorbability of carotenoid pigments is determined largely by the hydroxyl groups and not by the unsaturated, hydrocarbon portion of the molecules. With other adsorbents such as magnesia, adsorbability of the carotenoid pigments is determined by the unsaturated, hydrocarbon portion of the molecules as well as by the hydroxyl groups. Apparently different adsorbents attract different parts or regions of the complex molecules. Maximum separation of mixtures of similar pigments has been attained when the adsorbent attracts preferentially those structural regions that differ most. This relation between adsorbability and molecular structure may become a valuable

guide in the selection of adsorbents for use in adsorption columns.

THE SYNTHESIS OF ORGANIC MATTER BY *CHLORELLA* CELLS

In previous reports on this subject (Year Book No. 42, p. 83; No. 45, p. 109) mention has been made of a means of determining the degree of reduction of the total organic constituents of the cells of a *Chlorella* culture and of its designation by the term R-value. The concept of the R-value may be simplified somewhat by the realization that it is proportional to the heat of combustion.

In a mineral nutrient medium limited in available fixed nitrogen, *Chlorella* cultures reached higher yields and the cells were of higher R-value when they were supplied with 5 per cent carbon dioxide in nitrogen than when 5 per cent carbon dioxide in air was supplied. Also, it was noted that the yield and R-value of cultures grown in 5 per cent carbon dioxide in nitrogen continued to increase over long periods of time. A comparative study of cultures grown in these two gas mixtures demonstrated that with carbon dioxide in air the maximum yield and R-value were reached after 49 days of continuous illumination. For such cultures the yield of cells was 1.20 g. dry weight per liter and the R-value 58.72. A corresponding culture grown in 5 per cent carbon dioxide in nitrogen gave a yield of 1.63 g. dry weight per liter and an R-value of 61.87. In the cultures grown in the air mixture, after reaching a maximum, both the yield and the R-value decreased progressively with increased age. This is contrary to the experience with cultures supplied with carbon dioxide in nitrogen, in which the yield and R-value increased continuously with age up to 75 days. It is not known, however, how much longer such increase could be maintained.

Considering the different effects of age upon cultures in the two gas mixtures, as well as the fact that the maximum yield and R-value with air are less than with nitrogen for a culture of equal age, it is apparent that the very high yields and R-values attained in nitrogen cannot be reached in air. The extreme conditions are, of course, provided by cultures grown in a mixture of carbon dioxide and pure oxygen. Under these conditions very small yields of cells and low R-values are obtained. Whether these differences in the nature of the products formed by the *Chlorella* cells under aerobic and anaerobic conditions reflect differences in the course of the photosynthetic reactions, or whether the variation in the nature of the products results from subsequent metabolic reactions, is a subject for further investigation.

Another difference between cultures grown in mixtures of carbon dioxide and nitrogen and those grown in carbon dioxide and air appears in the effect of continuous and intermittent illumination. In cultures with nitrogen mixtures, essentially the same yields and R-values were obtained under equal time of illumination, whether this was continuous or intermittent. By contrast, in mixtures with air, intermittent illumination produced higher yields and higher R-values as compared with cultures receiving continuous illumination on a basis of equal hours of illumination. Thus, the maximum yield and R-value were reached after 49 days of continuous illumination and after 98 days of intermittent illumination of 12 hours in the light and 12 hours in the dark. The yield for the continuously illuminated cultures was 1.20 g. dry weight per liter of the culture with an R-value of 58.72, and for the intermittently illuminated cultures the yield was correspondingly 1.43 g. and the R-value 60.86. For other periods of time, extending to 154 days of intermittent il-

lumination, the continuously illuminated cultures, on a basis of equal time of illumination, were lower in both yield and R-value than the intermittently illuminated cultures. It is not without interest that the intermittently illuminated cultures in a mixture of carbon dioxide and air are still not equal to those grown in carbon dioxide and nitrogen in regard to yield and R-value.

Chlorophyll content of *Chlorella* decreases sharply as high R-values are attained. For example, the chlorophyll content of cells with an R-value of 50 may be but 10 per cent that of cells with an R-value of 40. At the highest R-values attained, the chlorophyll content may fall to less than 0.1 per cent of that of the dark-green cells of low R-value.

THE LIPIDS OF CHLORELLA

In an earlier report (Year Book No. 45, p. 111) was given the probable composition of *Chlorella* cells of different R-value, based upon calculations and certain assumptions. Mr. Milner has now carried out chemical analyses of the lipid fraction of this plant material. For this purpose larger quantities of cells of high R-value had to be cultured. The quantitative extraction of the lipins from this material is associated with some difficulties and entailed the development of special methods. In each case, the quantity of lipid obtained by solvent extraction agreed well with the value calculated from the R-value by the method just referred to. This confirms the conclusion that it is lipid accumulation which is mainly responsible for the increase in R-value of developing *Chlorella* cells.

As the R-value of the cells increased from 42 to 60, there was an increase in the fatty acid content of the lipid fraction from 28 to 87 per cent; this was accom-

panied by a decrease in the unsaponifiable fraction from 12 to 3.3 per cent. It is apparent from these figures that the increase in R-value of the cells is caused principally by the increase in the fatty acid content. The progressive decrease in unsaponifiable fraction as the R-value increases shows that no material accumulation of hydrocarbon has taken place.

The iodine number and neutralization equivalent of the total fatty acids show that, as the R-value of the cells increases, there is a small increase in the average molecular weight of the acids, and that this is accompanied by a definite increase in the degree of saturation. Both these trends tend to increase the R-value of the acids themselves. But the large increase in the R-value of the cells is principally due to the increased quantity of the fatty acids rather than to changes in the composition of these acids.

The fatty acids from each sample were fractionated by the lead salt separation and ester distillation methods. The fatty acids from *Chlorella* cells appear to be almost entirely C_{16} and C_{18} members of the series. With the quantities available it was not possible to estimate with any accuracy the minor amount of lower and higher fatty acids which may have been present. The principal saturated acid is palmitic, which varies between 8 and 17 per cent of the total. The quantity of stearic acid is small, 0.4 to 4 per cent. Unsaturated fatty acids comprise about 85 per cent of the total, there being 29 per cent of the C_{18} and 54 per cent of the C_{16} from low R-value cells, to 18 per cent of the C_{16} and 67 per cent of the C_{18} from cells of an R-value of 60.

The noteworthy feature of the fatty acids from *Chlorella* cells is the great unsaturation of the liquid acids, particularly of the C_{16} fraction. These acids had 2.05 and 2.18 double bonds per carboxyl group from cells of an R-value of 42.5 and 54.9 respec-

tively. The C_{18} liquid acids from the same two samples had 2.23 and 1.17 double bonds per carboxyl. Apparently the increase in saturation of the total fatty acids

with increase in R-value occurs in the C_{18} rather than in the C_{16} liquid acids. It is probable that there is little oleic acid in the cells of low R-value.

EXPERIMENTAL TAXONOMY

JENS CLAUSEN, DAVID D. KECK, AND WILLIAM M. HIESEY

A major research project extending over a period of five years has been brought to conclusion during the year with the submission for publication of a manuscript on "Environmental responses of climatic races of *Achillea*." This will appear as the third number in the series "Experimental Studies on the Nature of Species" (Carnegie Inst. Wash. Pub. 581). In it are detailed the results obtained from transplant experiments conducted in the climatic series of field stations across central California and from physiological experiments under controlled conditions, together with their implications (Year Book No. 45, pp. 112-117).

A complementary paper prepared by the late Professor W. E. Lawrence, of Oregon State College, shortly before his death in February 1947 further rounds out the story. This paper, "Chromosome numbers in *Achillea* in relation to geographic distribution," was prepared while Lawrence was a guest investigator at this laboratory. He had spent the year 1943-1944 and the summers of 1945 and 1946 here, working, in addition, on the climatic races of the tufted hair grass, *Deschampsia caespitosa*. He brought to our group his thorough knowledge of the classic approach to ecology. By combining with that the experimental approaches leading to the concept of climatic and other ecological races, his papers have contributed to modern ecology.

The bluegrass program, employing species of the genus *Poa*, has advanced materially during the year. This program, which is carried out in co-operation with

the Soil Conservation Service of the United States Department of Agriculture, explores the evolutionary avenues in a group of asexually propagating plants of value on western range lands. In it, basic scientific research and its practical application are combined.

Sixteen new Poas, all developed through hybridization between species belonging to different taxonomic sections and coming from very different climates, were sent for testing to the regional nursery of the Soil Conservation Service at Pullman, Washington, in the spring of 1946. These were studied in detail and compared with their parental species in June 1947 by Dr. Clausen in company with Dr. A. L. Hafenrichter and other members of the staff of the Soil Conservation Service. Several of these hybrids show promise, both on account of their favorable combination of characters and on account of their apparent ability to extend the length of the grazing season into the dry summer.

The response of the bluegrasses in the garden at Pullman differs from that of divisions of the same individuals growing in any of the three environments at the California transplant stations. Forms that grow poorly at Stanford may be vigorous at Pullman, and vice versa. From these preliminary tests we can begin to assign the new hybrids, with some confidence, to those kinds of climates to which they may be best fitted. Their fitness is largely predetermined by the characteristics of the parental species, which, in turn, are in harmony with their native climates. The

apparent success of hybrids between such remotely related species opens new possibilities to plant breeders for tapping unutilized sources of variation in wild grasses. Some of the superior wild strains used in these crossings had been saved from probable extinction by their introduction into the nurseries of the Soil Conservation Service.

Early in 1947 fifty-one additional hybrid strains from other *Poa* crossings were given to the Soil Conservation Service for testing. On the basis of this year's experience, some of these will be grown in the nursery at San Fernando, southern California, and others at Pullman. Their F_1 parents are under test at the three altitudinal transplant stations of the Institution. The San Fernando nursery is 25 miles from the coast at $34^{\circ} 15'$ north latitude; the Institution stations lie in a transect across central California near 38° north from near the coast to the crest of the Sierra Nevada; and Pullman is at $46^{\circ} 40'$ north in a continental climate well east of the Cascades. These plants are therefore subjected to tests in both a latitudinal and an altitudinal range of environments that should yield conclusions of both scientific and practical importance.

Seed of six of the more promising *Poa* hybrids were sent to the Scottish Association for Research in Plant Breeding at Edinburgh at the request of Dr. J. W. Gregor for winter-active grasses suitable for the mild coastal climate of western Great Britain. The trial plantings made there will further extend the range of climates under which the new *Poas* are tested.

THE PHYSIOLOGIC AND GENETIC BASES OF CLIMATIC RACES

A primary step in the evolutionary process is the organism's development of fitness

to a new environment. No plant can survive that is not timed in its development with the seasonal and diurnal rhythms of its climate. The evolution of such fitness is independent of, and precedes, the evolution of interspecific barriers. A species that occupies a series of climatically contrasting environments may therefore consist of many races. The analysis of the physiologic experiments on *Achillea* conducted by Dr. Hiesey in the controlled greenhouses at the California Institute of Technology has brought this clearly into focus. In the two species of *Achillea* that populate a transect across central California, a dozen or so climatic races can be distinguished, as described in the last report. Their periods of activity and dormancy are closely synchronized with the seasonal conditions in their native environments and are as different as are the climates of this varied topography. But among the most interesting racial differences are the requirements for different day and night temperatures, as brought out in the controlled greenhouse experiments.

These experiments show that members of one species from adjacent geographic areas but in different climatic zones may require very different temperatures and light conditions for their best development. *Achillea lanulosa* from a mid-altitude on the west side of the Sierra Nevada developed best under warm days and cold nights, conditions characteristic of the spring and early summer seasons in its native environment, when most of its growth is made. Forms from a similar altitude but on the Great Basin side of the Sierra Nevada develop most rapidly under warm days and warm nights. Alpines of the same species from the Sierran crest were not activated by either of these two sets of experimental conditions, but responded when additional light was sup-

plied. This is consistent with the higher light intensity found at high altitudes. On the other hand, the races of *Achillea millefolium* from northern latitudes in Denmark and Lapland are physiologically similar to the Great Basin race of *lanulosa* from so much farther south, for they also develop rapidly when both days and nights are warm. They and the Great Basin plants are so constituted that they can take full advantage of the brief, warm summers of their native environments.

In marked contrast with these, the *Achillea borealis* forms from the mild but uniformly cool California coast grow best under cool days and cold nights, but they grow slowly, coming from an environment with a long growing season. On the other hand, a giant race of this species from moist habitats in the hot San Joaquin Valley utilizes primarily the long summer for its growth, and, even under controlled conditions, develops most rapidly under warm days and nights.

Such differences in physiological behavior between plants that are morphologically so similar that taxonomists distinguish them only with difficulty reveal remarkably close correlations between their activity patterns and their native environments. The existence of such correlations suggests the manner in which natural selection must operate.

It is evident from these and other experiments that the balance between the plant and its environment is intricate, and that it may be attained in different ways. Such differences are controlled by heredity, as is shown by the genetic experiments on climatic races of *Potentilla glandulosa*. Furthermore, a suitable balance with any given environment may be obtained through very different heredities, and plants that have evolved different genetic mechanisms for controlling their physiology may not be able to exchange their

genes freely without disturbing the intricate developmental processes in their offspring. The organization of groups of plants into climatic races and into species, therefore, appears to depend upon genetically determined physiologic differences.

NEW HYBRID POAS FOR DIFFERENT ENVIRONMENTS

The working principles of this program and the previous progress have been discussed in Year Books Nos. 43, 44, and 45. Briefly, the basic idea has been to utilize the gene supply from a much wider source than that of the individual species in order to produce outstanding hybrids of agronomic importance. The inheritances of species fitting very different climates were combined to produce for intermediate climates hybrids having wider climatic tolerance than either parent. The probabilities of success in such an endeavor are enhanced by crossing forms that do not occur together in the wild; in those that occur together hybridization and natural selection have presumably already sorted out the best combinations. Advantage was also to be taken of apomixis as an aid in quickly establishing desirable new non-segregating hybrids.

The finding that two-thirds of the hybrids between apomictic parents were sexual, and only one-third apomictic, was unexpected. Some of the apomictic hybrids were rather highly sterile, also, and some were weak, but still others had qualities of promise. Compensation for the unexpected segregations was found in the great variety of recombinations obtained, many of which were very vigorous, affording much more opportunity for selection than in strictly apomictic forms.

Eleven species of *Poa* have been utilized in the crossings. These are *Poa ampla* Merr., *nevadensis* Vasey, *scabrella* (Thurb.)

Benth., *Canbyi* Piper, and *gracillima* Vasey, all west American bunch grasses; *P. pratensis* L., *compressa* L., *arida* Vasey, and *nervosa* Vasey, of the rhizomatous group; and the two more distantly related species *P. longifolia* Trin., a bunch grass, and *P. arachnifera* Torr., a dioecious rhizome grass. Forty different strains of

The first seven combinations listed in the table have been the most successful. Five species—*ampla*, *scabrella*, *pratensis*, *compressa*, and *arida*—enter into these. Of the 11 species tried in these experiments, then, these appear to have the gene sets (genomes) from which new forms can most successfully be synthesized. It is note-

TABLE 1
INTERSPECIFIC CROSSINGS IN POA

SPECIES COMBINATIONS	RACIAL COMBINATIONS		No of F ₁ PLANTS
	No tried	No suc ceeding	
1 <i>Poa ampla</i> × <i>pratensis</i>	10	10	162
2 <i>P. ampla</i> × <i>compressa</i> (and reciprocal)	3	2	9
3 <i>P. ampla</i> × <i>arida</i> (and reciprocal)	1	1	2
4 <i>P. scabrella</i> × <i>ampla</i>	2	1	3
5 <i>P. scabrella</i> × <i>arida</i> (and reciprocal)	1	1	5
6 <i>P. scabrella</i> × <i>pratensis</i>	14	8	56
7 <i>P. scabrella</i> × <i>pratensis</i> × <i>ampla</i>	2	2	10
8 <i>P. scabrella</i> × <i>compressa</i>	2	2	5
9 <i>P. scabrella</i> × <i>arachnifera</i>	4	1	1*
10 <i>P. Canbyi</i> × <i>pratensis</i>	2	2	3
11 <i>P. gracillima</i> × <i>pratensis</i>	1	1	12
12 <i>P. gracillima</i> × <i>scabrella</i> (and reciprocal)	2	2	18
13 <i>P. nevadensis</i> × <i>compressa</i>	4	1	4†
14 <i>P. nevadensis</i> × <i>longifolia</i>	1	1	1†
15 <i>P. nevadensis</i> × <i>pratensis</i>	1	0	0
16 <i>P. nervosa</i> × <i>scabrella</i>	1	0	0
17 <i>P. nervosa</i> × <i>Canbyi</i>	2	0	0
Totals	53	35	291

*Sterile

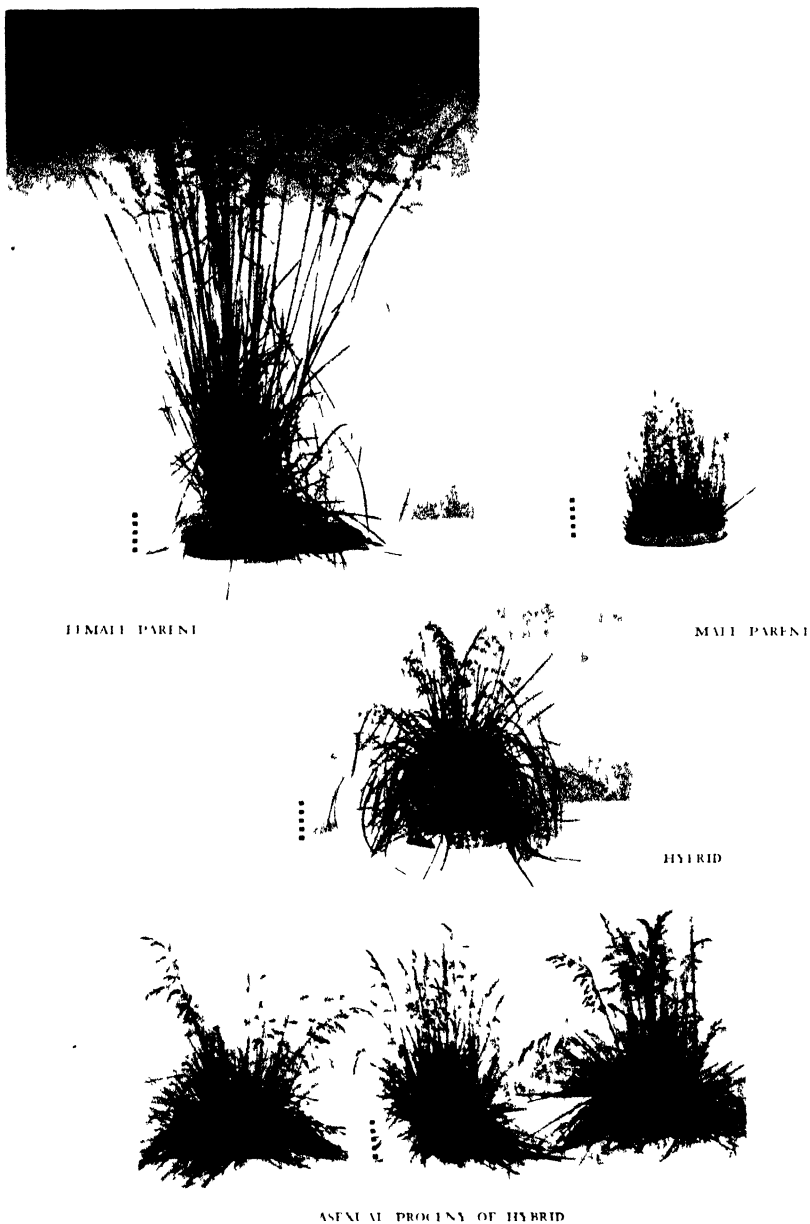
†Sublethal

these species, from very different climates, were used in the crossings. Of the 53 hybrid combinations attempted, 35 succeeded, resulting in 281 F₁ hybrids and 10 triple hybrids, obtained from among more than 52,000 seedlings. Fourteen different interspecific combinations were made, which are listed in table 1. Many of these were made several times, using different races.

worthy that it has been impossible to use Kentucky bluegrass, *P. pratensis*, as the female parent in any of the hybrids, although it was frequently used successfully as the male parent.

RESPONSES OF THE POA HYBRIDS TO DIFFERENT CLIMATES

The new hybrids resemble wild species in that they fit certain environments better



Big bluestgrass from Palouse Prairie, Washington; the subarctic form of Kentucky bluegrass from Swedish Lapland, and one of their nonsegregating hybrid lines. All these are shown as they grow at Stanford.

than others. Their practical utilization depends upon discovering to which climatic conditions they are best adapted. A few examples will serve to illustrate the kind of differences in climatic response that have been uncovered.

Poa ampla × *pratensis alpigena*. One of the most promising new Poas in the Pullman nursery is an apomictic 63-chromosome hybrid between a giant form of the big bluegrass, *P. ampla*, from near Pullman, and a subarctic form of Kentucky bluegrass, *P. pratensis alpigena*, from Swedish Lapland (plate 1). It is moderately vigorous even as far south as Stanford, but becomes much more productive farther north at Pullman. It is unlike any known species of *Poa*. At Pullman it is a freely tillering, very leafy form that has inherited from *ampla* glaucous herbage, large inflorescences, and winter-active habit, even when subjected to heavy frosts, and from *pratensis alpigena* rust resistance, increased tillering, rigid culms that do not lodge, and extended summer activity. This hybrid does not benefit by being moved from Stanford to the higher altitudes of the Sierran transplant stations, but from its performance at Pullman seems to be especially suited to more northern latitudes.

A 70-chromosome sister hybrid of the same parentage is morphologically very different. It is weak at Stanford, but at the mountain stations is stronger, and there it flowers freely. Unlike its apomictic sister hybrid, it is sexual and segregates freely in the second generation. At Stanford only 19 out of 300 second-generation seedlings survived, but at Pullman 80 per cent survived, and there, among others, very rhizomatous, summer-active, and late-flowering forms are segregated. Some of these derivatives combine the best characters from both parental species and are very vigorous. Two additional hybrids of the same parentage also proved to be stronger

at the mountain stations than at Stanford, but were not tested at Pullman. These results indicate that the hybrids between *Poa ampla* from eastern Washington and *P. pratensis* from Lapland require winters that are colder than those in the California lowlands.

Poa ampla × *pratensis*. A 96-chromosome spontaneous hybrid of this combination, originating in the Pullman nursery and discovered among seedlings grown at Stanford, was described in Year Book No. 44, pp. 76-77. It makes excellent growth at Stanford, much exceeding in vigor either parental species. It reproduces sexually, as is shown by the segregation among the second-generation offspring, which also grow vigorously at Stanford. At Pullman, however, this hybrid is less vigorous than at Stanford and less vigorous than its *ampla* parent.

An explanation of these different reactions in the two environments may be inferred from the characteristics of the parental forms, neither of which is native in the Stanford region. The *ampla* parent is unsuited to the conditions of the California coastal valleys, because during the warm, early summer it is heavily attacked by rust and can seldom mature seed. Forms of *pratensis*, likewise, are not ideally fitted to this environment, because the winter dormancy of this species places it at a disadvantage as compared with the winter-active native plants in this mild climate. When, however, the *ampla* and *pratensis* inheritances are combined in the hybrid, a winter-active grass is produced that is fairly resistant to rust and that remains active well into the summer, far outperforming either parental species at Stanford. At Pullman the more severe winters force the hybrid into dormancy, but the *ampla* parent remains active. The hybrid is thereby at a disadvantage and produces less total growth during the

season than its *ampla* parent. Here, then, are two species which, for different reasons, are unable to populate the Coast Ranges of central California, but whose hybrid is successful in this environment rather than at its place of origin in eastern Washington, where both species grow spontaneously.

Not all the *ampla-pratensis* combinations are winter-active at Stanford like the one described above. For example, a cross between the giant form of *ampla* from the Palouse Prairie near Pullman and a montane strain of *pratensis* from a meadow at Mather, at 4600 feet in the Sierra Nevada, yielded offspring that are for the most part winter-dormant. Moreover, all the 57 first-generation hybrids of this combination grew very vigorously in the very different climates of the Stanford, Mather, and Timberline transplant stations. At Stanford they undergo a short winter dormancy, but remain active during the dry summer when the native Coast Range races of *Poa* are forced into dormancy. Their very rhizomatous character and rust resistance are notable at this station. At Mather this population is even more uniformly vigorous and much more floriferous than at Stanford, a fact which indicates that it is generally better fitted to these montane conditions. At Timberline it survives with surprising success, breaking its winter dormancy more rapidly than do any of the other hybrids tried at that station and developing faster than those that are winter-active at Stanford. The vigorous, rapid development of this hybrid at the mountain stations and the relatively poor flowering of many individuals at Stanford suggest that it is better fitted for environments with colder winters. The individual variation within this population is such, however, as to make possible the selection of outstanding performers at any one of the three stations, for some indi-

viduals are winter-active and most vigorous at Stanford and others most vigorous at Mather. A study of the second-generation progenies now under way will provide more information regarding opportunities for selection in this combination.

These examples of differences in environmental responses provided by three hybrid combinations between different races of *Poa ampla* and *P. pratensis* illustrate the evolutionary possibilities in combining climatically different races of the same two species to produce forms suited to very different climatic niches.

Poa ampla \times *compressa*. Only a few high-quality grasses are available to provide grazing in the West during the summer months. Late flowering is associated with prolonged vegetative activity and is one of the best means of keeping a grass green during the summer. *Poa compressa*, the Canada bluegrass, is one of the latest-flowering species, and a hybrid between a form of it from the Mediterranean slopes of Asia Minor and a late-flowering Palouse Prairie form of *Poa ampla* is the latest of all the *Poa* hybrids. It remains green throughout the summer and is resistant to rust. Unfortunately, however, all except one of these hybrids are highly sterile. This fertile individual proved to be sexual and produced highly variable offspring, but the second hybrid generation was so weak at Stanford that only 80 out of 240 seedlings survived, and of these only 22 flowered. It was found that a sample of this second generation grown at Pullman was much more vigorous than that at Stanford, so that the apparent hybrid incompatibility in this case is influenced by the environment. Although some inferior forms appeared at Pullman also, approximately 30 per cent of the offspring were very vigorous grasses that had inherited the rhizomes, late flowering, and rust resistance of their *compressa* parent, and some of the size

and leafiness of their *ampla* parent. A highly desirable grass can probably be developed from this combination, but it would doubtless require a climate with a cold winter and a warm summer, such as is found in our Great Basin areas.

Poa scabrella × *pratensis*. This hybrid between the California bluegrass and the Kentucky bluegrass combines a winter-active, summer-dormant bunch grass with a winter-dormant, summer-active rhizome grass. Some 33 second-generation progenies of this combination have been studied, all from hybrids between a coastal southern California form of *scabrella* and races of *pratensis* from Lapland, Canada, the Sierra Nevada, and the Great Basin. Some of these progenies are apomictic, others are sexual and segregating.

In the garden at Stanford this hybrid is as winter-active as *scabrella*, developing culms in midwinter and flowering from late February through March. It and the apomictic, nonsegregating F_2 progenies are also moderately summer-active, thus lengthening the growing season over that of the *scabrella* parent by a month or two in the early summer and again in the fall; they are briefly dormant in midsummer. The *pratensis* influence has also increased the number of tillers considerably, although this hybrid cannot be classified as rhizomatous. The result is a freely tillering bunch grass that in the California Coast Range environment is more productive and stays green longer than the native *scabrella*.

Its sexual F_2 progenies are also winter-active, but they segregate summer-dormant and summer-active forms and also the entire gamut from strict bunch grasses to fully rhizomatous types. Some of the most promising of these segregants are summer-active and rhizomatous, having the advantages of an almost continuous growing season and a sod-forming habit.

Although these forms grow vigorously through the winter near the coast, where only light frosts occur, at Mather and Timberline the much lower temperatures force them into winter dormancy. As a consequence they are considerably weaker at these stations than at Stanford, although they are stronger than their *scabrella* parent. At Pullman, also, most of the *scabrella*-*pratensis* hybrids are forced into winter dormancy and are less vigorous than at Stanford, although still much stronger than their *scabrella* parent, which barely survives. The most successful hybrid of this combination at Pullman received its *pratensis* chromosomes from a Great Basin race coming from a climate not unlike that of Pullman. This hybrid was the only one of this combination that remained green through the winter at Pullman, and, accordingly, it had some advantage over the others.

These tests indicate that the present *scabrella*-*pratensis* combinations are best fitted for climates with mild winters, like those where *scabrella* is native. Here, from the agronomic viewpoint, it is superior to the *scabrella* forms, because of its extended season of growth. By using *pratensis* races from climates with severe winters, it may be possible to produce hybrids that can tolerate colder winters. Through selection in the progenies of sexual hybrids, it should be possible to develop winter- and summer-active rhizomatous grasses for the coastal slopes on the west sides of the continents, where the winters are relatively mild.

PARTIAL APOMIXIS: AN EVOLUTIONARY LABYRINTH

Most of the wild perennial Poas are partially apomictic, that is, they reproduce principally by seed formed without fertilization, but 5 to 10 per cent of their off-

spring differ in appearance from the uniform apomictic sister plants and presumably arise through the sexual process. Such aberrant individuals are regularly weaker than the normal apomictic offspring and accordingly are seldom seen in the wild. Aborted seed is also common in wild forms. Since the apomictic *Poa*s are chromosomally very irregular, it is probable that not only the weak aberrant seedlings, but also the aborted seed represent sexual offspring that are genetically so unbalanced that they are unable to develop.

Some apomictic species, such as *ampla* and *scabrella*, are only about 30 to 40 per cent fertile, whereas in others, such as *pratensis*, the seed fertility approaches 100 per cent. But even in *pratensis*, highly apomictic individuals may produce a small fraction of weak, sexual aberrants, and other individuals may be highly sexual. Thus it is evident that apomictic and sexual processes exist concurrently in this genus, and that apomictic and sexual fertility may vary independently.

Although the sexual process is still active in the apomictic *Poa*s, the apomictic type is maintained through selection, because the apomictic fertility is greater than the sexual, and the apomictic offspring are the more vigorous. In the wild only those apomicts survive which possess this kind of balance between the asexual and sexual processes. In the experiment field, however, we find that many new situations arise when one apomictic species is crossed with another. This can happen because under cultivation natural selection does not operate so rigorously on the new genetic combinations as it would in the wild.

In the garden, for example, some hybrid strains are predominantly apomictic yet so sterile that they could not maintain themselves under competition, although the offspring they do have are sufficiently vigor-

ous. One such apomictic strain, derived from some 15,000 seeds of a 59-chromosome *compressa* \times *ampla* hybrid, consisted of 53 vigorous plants of the apomictic maternal type and 13 weak, sexual aberrants. This is a fertility of only 0.44 per cent. A very different situation was found in one of the fertile hybrids of *scabrella* \times *pratensis* which was predominantly sexual. It produced 55 apomictic and 185 sexual offspring among a total of 240, and in this case the two kinds of offspring were about equally vigorous.

A weak apomict throwing some vigorous sexual aberrants was found in a 73-chromosome sister plant of the *ampla* \times *pratensis* *alpigena* hybrids already mentioned. This plant was predominantly apomictic, for 217 of 240 second-generation progeny were of the maternal type but so weak that only 70 survived the winter at Stanford and only a few were able to flower. In addition there were 23 variable offspring that had arisen by the sexual process. Most of these far outperformed the apomictic offspring, and one was outstanding—the best of all the hybrids of this combination—a tall, vigorous, many-culmed, very leafy and strongly rhizomatous individual. In this case there is a complete reversal of the situation characteristic of wild apomicts, for the apomictic offspring are weak and the sexual much stronger. This is an indication that even the weak apomicts may in time yield superior offspring.

It was mentioned that two-thirds of the hybrids between apomictic *Poa* species reproduce exclusively by the sexual process. Some of these are weak and rather sterile, others are weak but fertile, still others are strong but fairly sterile, and, finally, a few are fertile and have a high percentage of vigorous offspring.

In the sexual hybrid progenies of *Poa* not all the parental characters segregate completely. For example, all the second-

generation progenies of *scabrella* × *pratensis* were winter-active despite the fact that the *pratensis* parent was winter-dormant. The explanation of this unexpected observation probably lies in the fact that all the *Poa* species used in these crossings have high chromosome numbers, and there is independent evidence that their chromosomes are already much duplicated. In hybrids between such species, the chromosomes of each parent should be able to pair between themselves, preventing segregation of the characters determined by such duplicated chromosomes. This theory is supported by the observation that chromosome pairing is as extensive in the *Poa* hybrids as in the parental species. Both parents and hybrids have some unpaired chromosomes. Considerable segregation is possible on account of random distribution of these to the gametes.

The possibility exists in *Poa* that when hybrids between apomictic species are formed which reproduce sexually, these may in later generations produce apomictic forms again. From an evolutionary point of view and for practical breeding purposes such a situation would be of utmost importance, for a period of sexuality after crossing would be of benefit as a means of more thoroughly exchanging the parental characteristics.

Apomixis is a remarkable means of storing potentially great variation for possible later use in the evolutionary process. It would indeed be of considerable practical and theoretical importance were we able to break the apomictic bond periodically, releasing the variability and then sealing it up again after a period of recombination. The first of these steps has already been taken.

USE OF THE STATION FACILITIES

The natural opportunities for biological studies in the environs of the Sierran

transplant stations are increasingly being realized, and many biologists have visited the stations for various purposes. Dr. Th. Dobzhansky, research associate of the Carnegie Institution from Columbia University, has spent his third consecutive summer at the Mather station investigating native populations of the fruit fly *Drosophila* along the Sierran transect. This year he has studied the occurrence of these races in relation to season and altitude.

Dr. G. L. Stebbins, Jr., of the University of California, visited the transect from Mather to Timberline several times, studying the genetic races of blue wild rye (*Elymus glaucus*) and California brome (*Bromus carinatus*). He has also established small, uncultivated test plots in sun and shade at Mather for studying the establishment from seed of races and hybrids of *Bromus*.

Dr. Mogens Westergaard, of the University of Copenhagen, Denmark, visited Timberline station in order to study and preserve for cytological examination alpine plants that also occur, or have close relatives that occur, in Greenland. He was accompanied by Dr. F. W. Went, of the California Institute of Technology, who made a study of the dwarf alpine annuals there and collected seed for growing under controlled conditions.

A round-table discussion was held at the Mather station on the role of genetics, physiology, and environment in the evolution of natural local populations, climatic races, and species. Almost all the participants spent two days at Timberline station either preceding or following the session at Mather. Those attending included: Drs. Th. Dobzhansky, Columbia University; F. W. Went, California Institute of Technology; Mogens Westergaard, University of Copenhagen, Denmark; D. G. Catcheside, Cambridge University, England; M. J. Heuts, University of

Leuven, Belgium; G. L. Stebbins, Jr., University of California; Carl Epling, University of California at Los Angeles; Reed C. Rollins, Stanford University; Carl Sharnsmith, National Park Service, Yosemite; and Clausen, Keck, and Hiesey of the Institution staff.

Informal progress reports on current research programs of the participants brought out the diversity of patterns of fitness to environment of plants and animals, as well as the similarities in the ultimate objectives of the group. Emphasis was placed on the physiological development of the organism as synchronized with the periodicities of the environment, and on the genetic control of the physiological responses. Examples were taken from recent investigations on natural races of *Achillea*, *Potentilla*, desert annual plants, tomatoes, *Drosophila*, the stickleback fish (*Gasterosteus*), guayule (*Parthenium*), evening primroses (*Oenothera*), interspecific hybrids of *Poa*, and natural hybrids between wheat grass (*Agropyron*) and wild rye (*Elymus*); and from germination experiments at Mather on climatic races and hybrids of brome grasses.

A decision was reached to search for a group of plants having as nearly as possible ideal characteristics for co-operative investigations on genetics, cytology, physiology, ecology, and evolution. A feature of this conference was that cytogeneticists, physiologists, and taxonomists began to see clearly how the investigations in their respective fields contribute mutually to a comprehensible picture of how the evolutionary processes operate.

Other scientists who attended the Mather conference on evolution used the opportunity to advance their own botanical interests at the Sierran stations. Particular mention should be made of the representative collection of mosses and liverworts assembled in the Harvey Monroe Hall Natural Area around Timberline station by Dr. D. G. Catcheside, of Cambridge University, England, the first such from this area. All these investigations will contribute to the knowledge of the flora and the ecology of the Hall Area, a preserve established for scientific purposes some years ago by the Forest Service in which is found a characteristic sample of the high-altitude flora of the central Sierra Nevada.

PALEOBOTANY

RALPH W. CHANEY

Our studies during the past year have continued to place emphasis on the record of Tertiary forests in the John Day Basin of eastern Oregon. The Mascall and other Miocene floras of western North America are largely composed of genera which came in from the north. Cretaceous and Eocene ancestors of many deciduous hardwoods, such as *Acer*, *Alnus*, *Betula*, *Carpinus*, *Cercidiphyllum*, *Fagus*, *Quercus*, and *Ulmus*, lived largely at high northern latitudes; their migration southward in post-Eocene time is indicated by many fossil

records both in North America and in Asia.

It is therefore of particular significance to consider the time and place of appearance of the black oaks (subgenus *Erythrobalanus*) with deeply lobed leaves. They are first recorded in rocks of Lower Miocene age in the Gorge of the Columbia River east of the Cascades, and before the end of the epoch were among the most numerous trees. They have not been recorded much farther northward either in fossil or in living floras, and are wholly

unknown in Eurasia. Had they been members of the Arcto-Tertiary Flora, their remains might be expected to occur with those of oaks of other types in the Eocene of Alaska, and in the Miocene of China, where a flora including many holarctic plants has been found in Shantung; they should also be found in the modern forests of Asia, where other oaks are common. The only known ancestor of the deeply lobed black oaks has been recorded by MacGinitie in an Eocene flora from the foothills of the Sierra Nevada. This flora from Chalk Bluffs contains numerous genera which are believed to have migrated northward from low latitudes, and it is wholly possible that *Quercus jalapensis* came with them. Students of modern oaks have suggested a center of origin for the black oaks on the plateau of Mexico, where there are many living species; in any event, they could scarcely have come to Oregon from the north.

From Miocene time down to the present, black oaks have made up an important part of the forests in North America. More than most Tertiary fossils, they and other oaks provide an illustration of gradual speciation during geologic time, with suggestions both of divergence and of convergence into a meshlike pattern of development. Recent discussion with Professor E. B. Babcock and Professor G. Ledyard Stebbins, Jr. has indicated that the high variability of leaf form in *Quercus* is consistent with the genetic make-up of modern members of the genus. Like most widespread living plants, the oaks are heterogenic, including large numbers of biotypes which may be grouped into more or less distinct ecotypes. Ready interpollination by wind has tended to accentuate their heterozygosity, and great genetic variability is the result. Ultimately we may anticipate the extinction of many living

species, and the more restricted distribution of their survivors.

The beginnings of such local extinction and restriction may be noted during the later Tertiary history of the western United States. Whereas the Miocene record includes a wide range in leaf form among the black oaks, the floras of the Pliocene show reduction in numbers, in size, and in variability. Prevalence of semiarid climate over much of the western interior since the Pliocene, and of dry summers adjacent to the Pacific coast, seems directly related to the smaller size and reduced number of species of surviving black oaks as compared with their occurrence in the eastern United States under a continuing summer-wet climate. During the same time, oaks with small, thick leaves and an evergreen habit (subgenus *Protobalanus*) have greatly increased in numbers and range in California and Mexico. With the oaks as with other Tertiary trees, climate appears to have exerted a controlling influence over distribution, leaf characters, and survival. Climatic changes of the future may be expected to modify further the forests as we know them today.

A remarkable case of the survival of a forest with little modification from Middle Miocene time down to the present has been discovered during comparisons of the Mascall flora with existing vegetation. On the flood plain of the Wabash River in southern Indiana, most of the common trees such as swamp cypress (*Taxodium distichum*), red oak (*Quercus borealis*), shagbark hickory (*Carya ovata*), slippery elm (*Ulmus fulva*), and swamp cottonwood' (*Populus heterophylla*) have Miocene equivalents in the Mascall flora which lived thirty million years or more ago. Several genera recorded as fossils no longer live in Indiana, but the resemblance between these two units of vegetation is so

close as to permit more than usually accurate reconstruction of the Miocene climate and topography of Oregon.

As was suggested above, the vegetation of the Eocene at middle latitudes appears to have had its origin largely at the south. Preliminary studies of the Clarno flora from the John Day Basin are showing the presence of cycads and ferns, as well as broad-leaved evergreens, whose living equivalents are confined to low latitudes. The northward movement of these and other members of the early Tertiary forest, to which the group designation Neotropical-Tertiary Flora has been assigned, and

their southward shift later in the Tertiary period, constitutes another well documented record of plant migration under compulsion of climatic change. Lingered behind, certain of the hardier members of the Neotropical-Tertiary Flora, such as *Lindera*, *Cedrela*, and *Oreopanax*, were absorbed by the Miocene floras from the north. Together with the black oaks above mentioned, these southern genera illustrate the manner in which plants from more than one center of origin may become mingled in a fossil flora, and suggest an explanation for the survival of certain aberrant trees in the forests of today.

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DEPARTMENT OF EMBRYOLOGY

Baltimore, Maryland

GEORGE W. CORNER, *Director*

The Department of Embryology is happily able to report a year of undistracted work, during which all the members of the Department have been present and with a number of competent younger associates and guests have been engaged upon their respective parts of our program of investigation. The details of their work will be reported below.

In December 1946, Dr. Margaret Reed Lewis retired from the Carnegie Institution. Dr. Lewis was appointed "collaborator" on January 1, 1915, and thereafter until the current year was continuously engaged in research in the Department of Embryology. Her numerous valuable contributions have dealt with problems of blood cells and connective-tissue cells in tissue culture, with various aspects of experimental cytology of the living cell, with vital staining, problems of growth and immunity in malignant tumors, and other related topics in the field of normal and abnormal cytology. In 1940, when Dr. Warren H. Lewis retired from this department and joined the staff of the Wistar Institute for Anatomy and Biology in Philadelphia, Dr. Margaret Lewis transferred her work to the Wistar Institute, remaining however a member of the Carnegie Institution. It is a pleasure to add that arrangements have now been made for Dr. Lewis to carry on at the Wistar Institute her investigations in immunity and resistance of cancer cells, which have attracted international attention.

The staff now consists of five senior investigators, including the Director. Associated with these is a varying number (usually four or five each year) of fellows, guest investigators, and other persons giv-

ing their full time to research in the laboratory, and several medical students and other guest investigators giving part time to research.

Dr. Walter S. Wilde, who joined the staff in 1944 as assistant and collaborator of Dr. L. B. Flexner, resigned in March 1947 to accept a very favorable appointment in the National Institute of Health. During his relatively short connection with the Department of Embryology, Dr. Wilde proved himself a fertile and stimulating investigator.

Washington Buño, M.D., professor of histology and embryology in the University of Montevideo, spent the year from May 1946 to May 1947 in the Department on a Guggenheim fellowship. His work on early abnormal embryos will be reported below.

L. J. Wells, Ph.D., associate professor of anatomy in the University of Minnesota, came as Guggenheim Fellow from January to May 1947.

Dr. S. Culver Williams, assistant professor in charge of dental anatomy in the University of Pennsylvania, devoted two months in the summer of 1946 to the study of early development of the teeth. Dr. E. Carl Sensenig, at the time connected with the Department of Anatomy in Tulane University, New Orleans, returned in the summer of 1946 as in the previous years, to work on the embryology of the spinal column.

Mrs. Poldi Grabherr, staff photographer of the Chilean National Department of Health Laboratory, Santiago, spent a fortnight in the laboratory observing technical methods in scientific photography.

PROGRAM OF INVESTIGATIONS

Morphological studies. Dr. C. H. Heuser, curator of the Embryological Collection, has continued during the year his investigations on early stages of primate embryos. In particular, he has prepared a model and made intensive studies of a human embryo lent to the Department by Professor Bradley M. Patten, of the University of Michigan. This is of special value in connection with the problem of the origin of the yolk sac in man, a question that has been much debated in recent years, and to which it is hoped the embryos of the second week being accumulated in this laboratory will ultimately give a clear answer. Dr. Heuser has also given considerable time to the study of the early baboon embryos obtained at Johannesburg by Dr. Joseph Gillman (see below, "Co-operative activities").

Dr. George L. Streeter has completed another two stages of his extensive work on horizons of development (see recent previous Year Books), and has devoted much time, during the year just past, to a study of the development of bone in human embryos, with special reference to the time sequence of the stages of development and their relation to the growth and differentiation of other organs.

Dr. Elizabeth M. Ramsey, of Washington, has been spending two days each week in the laboratory for several years except when interrupted by her wartime service at the National Research Council, making an intensive study of the development of the blood vessels of the placenta of the rhesus monkey. For this work a number of monkeys were especially bred by Dr. C. G. Hartman and later by Dr. Corner, and the placentas at selected stages of pregnancy were prepared for study by injection of the blood vessels with India ink. Dr. Ramsey has completed her ar-

duous work on this subject, which will appear in volume 33 of Contributions to Embryology with drawings by Mr. Didusch based on intricate plastic-sheet models by Dr. Ramsey.

Dr. Washington Buño devoted about half his time to studying a collection of abnormal early embryos of the rhesus monkey that were set aside by Dr. Heuser when he and Dr. Streeter were making their comprehensive study of the normal embryology of rhesus (Contributions to Embryology, no. 181, 1941). The material thus placed at Dr. Buño's disposal is unique, because the embryos were bred in the laboratory by Dr. Hartman and are accompanied by breeding data, by the endometria, and in many cases by the ovaries, so that the condition of the uterus and corpora lutea may be studied.

Dr. Sensenig continued his investigation of the embryology of the human vertebral column, which he proposes to carry on to deal also with the anomalies of development, many of which, e.g. spina bifida, are of importance in surgery.

Dr. Wells undertook a study of one of the most complicated topics in human embryology, the development of the diaphragm and the pleural cavities. Dr. F. P. Mall, founder of this Department, was deeply interested in the same subject and wrote what was the standard contribution in his day. Dr. Wells has been able to re-investigate the same embryos that were used and illustrated by Mall, comparing them with many newer specimens. In work of this type the command of modeling techniques possessed by the staff of the Department is of especial value. Dr. Wells' models were demonstrated at the April meeting of the American Association of Anatomists. An article based upon them will be published later.

Mr. Lawrence R. Wharton, Jr., of Johns Hopkins Medical School, working under the guidance of Dr. Streeter and Dr. Burns, completed an account of a case of duplication of the ureter in an embryo of the collection, comparing it with a second, less advanced anomaly of the same sort generously placed at his disposal for study by Dr. S. I. Kornhauser, professor of anatomy at the University of Louisville.

Collection of very early human embryos. Dr. Arthur T. Hertig, of Boston, research associate of the Carnegie Institution of Washington, and his colleague Dr. John Rock have submitted a report on their work done under a special grant from the departmental budget, from which the following is excerpted:

During the past year twelve uteri obtained at operation, and thought likely to contain early embryos, have been studied. Most of the effort was concentrated on seeking preimplantation phases of the human embryo. Two such specimens were found free in the uterine cavity. The younger specimen (no. 8450) consisted of eight blastomeres arranged in a discoid instead of a spheroid form as normally expected, and is considered to be abnormal. The associated endometrium and corpus luteum indicated that the ovum was about $3\frac{1}{2}$ days old. Coital data were not inconsistent with this estimate, but not precise enough to be of much use.

The older specimen (no. 8452) was composed of twelve blastomeres of various sizes, shapes, and staining densities arranged in the customary spheroidal fashion. The specimen, which is estimated to be 4 days of age, was found on the 18th day of the menstrual cycle. As in the previous specimen, coital data are consistent but not critically useful.

It will be recalled that in 1943 a free nine-cell morula (no. 8190) was discovered in the uterine cavity on the late 17th or

early 18th day of the menstrual cycle. Although this specimen is probably abnormal, these three specimens, constituting as they do the only preimplantation stages of the human ovum thus far observed, tend to prove that the segmenting ovum reaches the uterine cavity early on the 4th day after ovulation (and fertilization). At this stage it has approximately six to eight blastomeres and as yet shows little if any segmentation cavity. It still has a vitelline membrane.

That two and indeed possibly all three of these very early human embryos are probably abnormal is not surprising. Dr. Corner has shown that in pigs about 30 per cent of all embryos are abnormal, and that one-third of these are already defective in the phase of segmentation. Thus, ability of an ovum to implant, even though it is or subsequently becomes defective, probably requires more robustness of the embryo than does mere segmentation. Hence the "very bad eggs" are weeded out in this phase of development and will therefore be proportionately more numerous among these very early embryos than among those which have the ability to implant on the endometrium. It will be recalled that of the 23 implanted human ova found by Hertig and Rock in the past nine years, almost 40 per cent show some abnormality, often of such a serious nature that it is incompatible with normal continuation of the pregnancy.

Experimental embryology. Dr. R. K. Burns has continued the study of opossum embryos (pouch young) subjected to experimental treatment with sex hormones. He was able to resume on a small scale the program of new experiments, which had become impossible during the latter part of the war period because of the unavailability of experienced trappers.

Miss Faith Wilson, fellow in zoology at Johns Hopkins University, has been as-

signed to this Department to do her thesis work under the direction of Dr. Burns and has made our laboratory her headquarters during the past two years. Miss Wilson is studying certain phases of embryological development of reproduction in the Syrian hamster, *Cricetus aureus*. This little animal, similar to the rat in its anatomical structure, has the shortest gestation period known among mammals (except the marsupials). Its young, born only 16 days after ovulation, are in some respects quite immature at birth. This is particularly true of the reproductive system, which is the object of Miss Wilson's research. The testis and ovary do not exhibit the kind of internal structure which indicates endocrine function until about 25 days after birth. The chief aim of the investigation is to study the degree to which the sex pattern of the accessory sex organs may be altered, during their relatively indifferent early stages, by administration of sex-gland hormones and by early castration. An effort is also being made to find out whether the adrenal cortex influences the differentiation of the accessory sex organs. For this study the hamster has another advantageous peculiarity: in the newborn female certain rudimentary male structures are more than ordinarily well developed. The female hamster develops good-sized corpora cavernosa, a relatively large glans clitoridis, an os priapiis, and even a rudimentary prostate gland. If the adrenal cortical hormone is androgenic, the female hamster offers a test object in which such an androgenic property should show its effects with especial readiness. Miss Wilson's studies are progressing well and will, no doubt, reach publication in her doctoral dissertation.

Dr. L. J. Wells, who before coming to visit the laboratory developed an ingenious method of removing the hypophysis of the fetal rat by operation in utero, attempted a similar operation in two mon-

keys with the assistance of Dr. Corner and Mr. Rever, who have had much experience in abdominal surgery in the monkey. Success in hypophysectomizing the fetal monkey would contribute much to our knowledge of the effect of the pituitary gland in fetal growth. The relatively long term of gestation, and the thorough knowledge of the proportions and weights of fetal and neonatal monkeys with which experimental material could be compared, made the enterprise tempting; but formidable technical difficulties were encountered and it does not seem profitable to continue along this line at present.

Biophysics; growth; enzymes. The program of investigation of the physiology of the placenta as an organ of transfer, led by Dr. Louis B. Flexner, was explained at some length in Year Books Nos. 41 (1941-1942) and 43 (1943-1944). As was mentioned in last year's report, these researches and associated studies on the still broader questions of the permeability of blood capillaries elsewhere in the body, and the distribution of water in the tissues, have been resumed after a lapse caused by the war. The Department of Embryology has been fortunate in having the active cooperation of the Department of Terrestrial Magnetism.

Dr. Gilbert J. Vosburgh, of the Department of Obstetrics of the Johns Hopkins University and Hospital, has actively participated in the studies on general and placental permeability. Dr. Louis Hellman, a senior member of the same department, has collaborated in consultation and by the provision of clinical material. Dr. Roy O. Scholz, of the Wilmer Ophthalmological Clinic at Johns Hopkins, has taken part in studies on general permeability and especially on the transfer of fluids in the chambers of the eye.

Dr. Flexner is also conducting research under a grant from the Committee on

Growth, National Research Council, acting for the American Cancer Society. The general aim of this program is to investigate the morphological and biochemical changes which occur in cells during embryonic growth, to correlate these changes, and to relate them to the onset of characteristic functions in an organ. The liver and cerebral cortex of the embryonic guinea pig are now being investigated from this viewpoint. With Virginia Peters, on leave from the National Cancer Institute, quantitative cytologic analyses of liver and cerebral cortex are being made for the purpose of determining what proportion of the growth of these organs is due to the increment in volume of their several constituent morphological parts: hepatic cell cytoplasm, hepatic cell nucleus, extravascular blood-forming cells, and extracellular space in the case of the liver; nucleus and cytoplasm of nerve cells and extracellular space in the case of the cortex. Biochemical investigations with J. B. Flexner have as their major aim an evaluation of the energy-rich phosphate compounds (creatine phosphate, adenosine di- and triphosphates) as they may be related to rate of growth and to degree of morphological and functional differentiation. The first step is to investigate the activity of phosphatases which are concerned, according to current concept, in liberating energy from these compounds. The critical time in the development of adenosine triphosphatase activity in cerebral cortex and liver is at about the 42d day of gestation (term 66 days). Prior to this time the activity of the enzyme is at a constant and low level. At the 42d day the activity begins to rise sharply to reach the adult level at birth. Acid phosphatase in the cerebral cortex is at a constant level of activity during the whole of that period of gestation which has been studied, and is about twice as active per unit dry weight of tissues as in the

adult. The activity of acid phosphatase in the liver at all stages of gestation is greater than in the cerebral cortex, and unlike that in the cortex is relatively low up to a gestation age of about 42 days, when it begins to increase to the adult level, reached at birth.

Physiology of gestation. Dr. S. R. M. Reynolds has continued his comprehensive study of the physiology of the pregnant uterus and of the fetus. The results of this study are now appearing in various scientific journals. A summary of those articles which were published during the year will be found below, in the section on "Published research." Dr. Reynolds has found that calculable hydrostatic forces in the uterine tissues play a large part in the reduction of local blood flow. These forces depend upon the characteristics of growth of the uterus, the shape of the products of conception, and the prevailing hormonal relations of the ovary and placenta. Detailed studies of the rearrangements of the blood vessels of the uterus during pregnancy have shown how these interrelations operate. Investigations of this sort point the way toward better understanding of the problems of advanced pregnancy and of the mechanisms concerned in the onset of parturition. Dr. Reynolds has also studied the anatomy of the blood vessels of the ovary, utilizing the beautiful technique of injection with a colored plastic substance (vinylite) followed by removal of the tissues by digestion with acid pepsin, leaving the blood vessels, or rather a cast of them in durable plastic. The results of this study of the ovarian vessels are summarized below under "Published research."

Dr. Reynolds has devised and constructed, with the aid of Mr. Heard, of this Department, and of engineering firms (in particular the Statham Laboratories, Inc., Los Angeles, California), an instrument for recording the contractions of the

late pregnant and parturient human uterus. By the use of ingenious devices employing "strain gauges" which are highly sensitive to local pressure, and which can be applied to the patient's abdomen, the contractions of the underlying uterus may be detected at several places at once and may be recorded on a paper tape. The apparatus is expected to be useful in studies of normal and abnormal parturition, and will be put into use at once in the Woman's Clinic of Johns Hopkins Hospital in collaboration with members of the Department of Obstetrics, Johns Hopkins University.

Mrs. Lyla T. Bradin, a graduate student of zoology at Johns Hopkins University, has been working under the direction of Dr. Reynolds, with financial support from the Ciba Corporation, of Summit, New Jersey. Her investigations deal with the susceptibility of newborn animals to oxygen deprivation. It is obvious that the sudden substitution, at birth, of air breathing for intrauterine respiration of oxygen borne by the mother's blood is a change to which critical adjustments must be made. The young of various species differ widely as to the degree of maturity at birth, and the response to oxygen deprivation appears to be an index of maturity. Utilizing this index, correlation is being sought between it and conditions existing in the uterus before birth, chiefly as these are affected by the shape of the conceptus. Promising results are being obtained, which will be published at a later time.

Dr. Irwin S. Kaiser devoted part of his time during the year to a study, under the general direction of Dr. Reynolds, of the effects of certain hormones and drugs, i.e. the estrogens, acetylcholine, atropine, and the antihistaminic substance pyribenzamine, upon the blood flow through the uterus. The observations, which were made chiefly upon grafts of uterine tissue growing in the anterior chamber of the

eye of the rabbit, have yielded information bearing upon the theory of the menstrual cycle, part of which is detailed below under "Published research."

Histology and physiology of the reproductive cycle; experimental teratology. Dr. George W. Corner, director, has continued his studies on the histology of the ovary. Ovaries from women of known reproductive history, collected by Dr. E. J. Farris, of the Wistar Institute, have been subjected to study and are yielding information as to the structure of the early human corpus luteum at successive stages of development. Dr. Corner has also been collaborator with Dr. Buño and Dr. Kaiser in the studies next to be reported.

Dr. Buño and Dr. Corner began during the year an experimental attack on the problem of prenatal mortality in mammals. Using rabbits, which are especially suitable for such experiments, the attempt was made to produce an unfavorable environment for the early embryos by introducing toxic substances into the mother's blood stream. In a relatively large number of experiments, a few anomalies of development were produced, presumably as a result of the experimental procedure. Since Dr. Buño's departure in May, Dr. Corner has continued the work.

At Dr. Corner's suggestion Dr. Kaiser took up and expanded some unpublished experiments of Dr. Corner on the action of the drug prostigmine upon menstruation in the rhesus monkey. In recent years a number of physicians have reported that this drug will bring on menstruation in women when the flow is delayed. Dr. Corner conceived the idea of trying prostigmine on rhesus monkeys during the summer, when menstruation is generally in abeyance. The negative results of his tests were confirmed by Dr. Kaiser, who also tried the effect of prostigmine upon spayed monkeys treated with estrogen,

with and without progesterone in various combinations. The menstruation-inducing action of prostigmine reported in women has therefore not been confirmed for monkeys in the special circumstances under which these experiments were done. Subsequent tests by Dr. Corner, in part on the same individual monkeys, show that they are capable of menstruation-like bleeding in the summer, if given a brief course of treatment with progesterone. Sudden termination of such treatment is usually followed by menstruation-like bleeding.

Dr. Kaiser also undertook a study of the arteries of the uterine lining (endometrium) in various species of primates, using material from the Department's collection and also a number of specimens provided by courtesy of the Department of Anatomy, Harvard Medical School. He found that certain New World monkeys which are stated to undergo periodic

breakdown of the endometrium resembling menstruation do not have intricately coiled endometrial arteries like those observed in Old World primates (human, chimpanzee, rhesus monkey, etc.). It is thus probable that the coiling is not *per se* necessary for cyclic hemorrhage.

A paper by Dr. Kaiser on this subject, offered in competition, won the Foundation Prize of the American Association of Obstetricians, Gynecologists and Abdominal Surgeons, awarded in September 1947.

Cerebral blood vessels. Mrs. Dorcas H. Padget, whose monograph on the development of the cerebral arteries of man will appear in volume 32 of Contributions to Embryology, is now working on a similar study of the later development of the cerebral veins, under a grant made to Dr. Corner for the purpose by the Life Insurance Medical Research Fund.

CO-OPERATIVE ACTIVITIES

The co-operative association with Dr. Joseph Gillman, of the University of the Witwatersrand, Johannesburg, South Africa, mentioned in Year Book No. 44 has continued. During the past year Dr. Gillman sent two more baboon uteri. That these both proved not to contain embryos was disappointing, but not altogether a surprise, for all investigators who have attempted the breeding of very early mammalian embryos have obtained a certain proportion of infertile mating. Although the fund provided for this work by the Carnegie Corporation of New York has been expended, the facilities set up in Johannesburg will continue, it is confidently expected, to furnish material for embryological studies. Dr. Gillman visited the laboratory again in July 1947, at which time plans were laid for continuation of the effort to obtain implantation stages of

the baboon. Meanwhile the embryos previously sent by Dr. Gillman have all been serially sectioned and are under study by Dr. Heuser, as mentioned above.

Co-operative enterprises carried on with Dr. A. T. Hertig and Dr. John Rock, of Boston, with the Johns Hopkins obstetrical and ophthalmological clinics, and with the Department of Terrestrial Magnetism of the Carnegie Institution have been mentioned in the section on "Program of investigations."

The facilities of the monkey colony have been made available for experiments by Dr. Roger B. Scott, of the Department of Gynecology, Johns Hopkins Hospital, on the experimental production of endometriosis, a subject close to the interests of this department. As in former years, we have housed several monkeys which are subjects of a long-continued and thus far

negative experiment on the production of tumors in monkeys by estrogenic hormones, begun by Dr. C. F. Geschickter in

consultation with Dr. Carl G. Hartman when the latter was a member of the Department.

THE CONTRIBUTIONS TO EMBRYOLOGY

Since the foundation of the Department of Embryology it has been the custom to publish many of the completed investigations in a series of Contributions to Embryology. The Contributions include suitable articles written by our own immediate staff, by our colleagues in the Department of Anatomy of Johns Hopkins University when relevant to the Carnegie program of research, by visiting investigators, and in rare cases by outside authors, if they have used material from the Department's collections or in some other way have been especially associated with the Department. Experimental work in physiology and biophysics from the Department laboratories not requiring elaborate graphic illustrations is published in the special journals of those branches of science.

Manuscripts for volume 32 were turned over to the Office of Publications in July 1946. Owing to wartime conditions, some of them had been in hand, awaiting clearance of volume 31, for as much as two years. The volume was almost ready for press at the end of June 1947 and will doubtless appear before this annual report is circulated. Inasmuch as the printing of the Contributions to Embryology is expensive and the edition, both of bound volumes and of reprints, is therefore limited, the contents of the long-delayed volume will be summarized here for the benefit of professional readers who may wish to know what is forthcoming.

The articles are as follows:

207. George W. Corner, *Alkaline phosphatase in the ovarian follicle and in the*

corpus luteum. The conclusions were summarized in the annual report for 1944-1945, Year Book No. 44. Preliminary note in *Science*, vol. 100, pp. 270-271, 1944.

208. Harold Speert, *The normal and experimental development of the mammary gland of the rhesus monkey, with some pathological correlations*. This is a comprehensive report with 19 plates dealing with problems not dealt with or only tentatively discussed in Dr. Speert's several papers in various journals 1940-1942 (see *Index Medicus* for references).
209. Emil Witschi, *Migration of the germ cells of human embryos from the yolk sac to the primitive gonadal folds*.
210. Joseph Gillman, *The development of the gonads in man, with a consideration of the role of fetal endocrines and the histogenesis of ovarian tumors*.

These two articles, written by well known investigators on the basis of studies made during visits to the Carnegie laboratory, provide definitive accounts of the embryology of the gonads and the germ cells in man.

211. George L. Streeter, *Developmental horizons in human embryos. Description of age groups XV, XVI, XVII, and XVIII*. Third of the series mentioned in Year Book No. 44, bringing the survey and classification of the human embryos of the Carnegie Collection down to about 36 days ovulation age.
212. Dorcas Hager Padget, *The development of the cranial arteries in the human embryo*. Illustrated by comprehensive graphic reconstructions. Mentioned in Year Book No. 44.

PUBLISHED RESEARCH

PHYSIOLOGY OF THE UTERUS

During the year 1946-1947 the work of Dr. Reynolds on the physical forces involved in accommodation of the uterus to the growing products of conception (embryo, placenta, membranes, and amniotic fluid) yielded valuable results which he has published in the anatomical, physiological, and obstetrical journals (see bibliography below). A summary of these results was presented at the annual meeting of the American Physiological Society. The following résumé is based largely on a general discussion which Dr. Reynolds published in the *American Journal of Obstetrics and Gynecology* for June 1947, and which sets forth in full detail the concepts he has developed.

The work has been done on the rabbit. To make subsequent statements clear, the reader should be reminded that in this species the embryos are spaced along the two tubular horns of the uterus. As they grow, each embryo causes local enlargement of the surrounding uterus, in approximately spherical form, so that each uterine horn bears a series of nodular enlargements. When pregnancy is about two-thirds advanced (about day 22), the conceptuses no longer increase in diameter, but enlarge lengthwise, so that the entire uterine canal is filled out by the now roughly cylindrical conceptuses, and the uterine horn itself is no longer nodular but cylindrical.

From his geometrical analyses and calculations Reynolds points out that the significant feature of this change of shape, as it is related to pressure within the conceptus and to the flow in the uterine walls, is that in the last third of pregnancy the radius of curvature of the transverse section of the uterine horn no longer changes. When the single-chambered uteri of the

rhesus monkey and the human species are similarly measured, it appears that a similar change of form of the enlarging uterus takes place at approximately the same proportionate phase of gestation. It is possible and indeed likely that the analysis made by Dr. Reynolds will help to explain the physiological and pathological phenomena of uterine accommodation in women.

Dr. Reynolds has measured the rate of blood flow in the pregnant rabbit's uterus by the ingenious method of injecting a small dose of cyanide into the uterine veins and recording the time required for the poison to reach the carotid sinus and cause a respiratory gasp.

He finds that the local circulation of maternal blood in the uterus about the conceptus decreases gradually as the latter increases in size. Suddenly, as the conceptus reaches maximum spheroid size, a profound decrease in uterine circulation (i.e. ischemia) takes place. As soon as the conceptus changes shape, by elongation, the rapid circulation of maternal blood is restored.

Hydrostatic forces within the uterus are also related to the shape of the conceptus. While the latter is spheroid the radii increase, with growth, in three dimensions, but after it becomes cylindrical only the lengthwise dimension increases. By simple calculation it is shown that the tension of the wall now increases in linear rather than in geometric proportion, thus easing accommodation of the uterus to its contents during the period of greatest absolute growth of the conceptus.

Reynolds has shown previously that the growth of the uterus itself, necessary to enable it to contain the conceptus, occurs chiefly during the period of maximum uterine tension. Consequently, after the change in form, the uterine tissue, already

sufficiently increased in amount, is "paid out" as it is stretched.

It is further shown by use of perfected technical methods (plastic corrosions) that the uterine ischemia, mentioned above, and its ensuing relief follow a pattern which may be explained on the basis of the hydrostatic forces and that the arrangement of the uterine arteries and veins is such as to make them readily adaptable to the abrupt change of form. There is reason to believe that rabbit, monkey, and human have in common the feature that during the phase of principal elongation of the uterus, conditions are such that local tension of the tissues about the region of entry and exit of the uterine blood vessels is held to the lowest possible level compatible with rapid enlargement of the fetus.

The period of transitory ischemia just before the change of form is a time of special danger to fetal nutrition.

Expulsive force of the uterus. At the 1947 meeting of the American Physiological Society, Dr. Reynolds and Dr. Kaiser presented the results of experiments in which the highly sensitive strain-gauge dynamometer was adapted to measure the absolute expulsive force of the uterus (of animals). The report concerned itself with the apparatus and technique.

Physiology of the endometrial blood vessels. At the same meeting Dr. Kaiser discussed the effects of certain drugs and hormones on the blood vessels of the endometrium in intraocular grafts. Both atropin and estrogens were found to halt the rhythmic activity of the vessels. Estrogens also cause dilatation and increase the number of functioning capillaries. Atropine does not prevent or reverse the action of estrogens in this respect. These observations necessitate a revision of the so-called cholinergic concept of the acute action of estrogens on the endometrial vessels. The increase in acetylcholine content of the

whole rabbit uterus observed following estrogen administration is probably due to changes in the myometrium. A different mechanism must be invoked to account for the phenomena seen in the endometrium.

The possibility that estrogens act on endometrial blood vessels, dilating them, by means of local production of a histamine-like substance can be explored, as Dr. Kaiser also reported to the American Physiological Society, by the use of anti-histaminic agents. One of these, pyribenzamine, is found to cause no change in the color of a piece of endometrium growing in the anterior chamber of the eye and under the influence of estrogen from the animal's ovaries. It does, however, produce an increase in the frequency and duration of contraction of the myometrium in the graft. The implication, which requires further study, is that the active circulation in the small endometrial vessels, under the influence of estrogen, is not caused by histamine.

THE OVARIAN ARTERY

Using the vinylacetate corrosion method, Reynolds has demonstrated, in the rabbit, the previously unnoticed fact that the ovarian artery runs through the hilum of the organ in a conspicuously spiral course. From the coils of this spiral artery, secondary branches carry blood to the tissues of the ovary. Two suggestions are offered as to the functional value of this striking arrangement:

(1) The coiling may serve to allow for orderly lengthening of the artery as the ovary is enlarged by successive pregnancies. This hypothesis has been tested experimentally by Dr. Reynolds (*Endocrinology*, June 1947; see bibliography below) by causing the rabbit's ovaries to grow rapidly by injection of gonadotrophic hormone. The spiral arteries were found to undergo

wider spacing of their coils, with extension of the loops so that two or three days after the stimulating injections the coiling had been altered to mere sinuosity.

(2) The coiling may serve to bring about orderly and rapid reduction of the blood pressure in the artery. It follows from this that irregularities in the pattern of the ovarian artery may contribute to the development of pathological states of the ovary. This possibility receives a certain degree of confirmation from the observations of Reynolds on rabbits' ovaries in which hemorrhagic cysts of some of the corpora lutea occurred as a result of stimulation with gonadotrophic hormone. In these ovaries the injection-corrosion preparations of the blood vessels showed distortions of the coiled arteries in the vicinity of the cysts. It is suggested that distortion of the spiral artery may contribute to development of the cysts by permitting the transmission of excessive blood pressure during the growth of the ovary under the influence of gonadotrophic hormone.

PERMEABILITY OF THE PLACENTA

During the current year another contribution on placental permeability has been published by Drs. Walter Wilde, Dean B. Cowie, and Louis B. Flexner. Previous studies of the group led by Dr. Flexner have been devoted to comparing the permeability of placentas of the four principal types found in mammals. For this purpose radioactive sodium was used as the test substance. A striking systematic difference in permeability, related to the known differences in structure, has been demonstrated.

The next step is to study the permeability of the placenta to various substances which normally occur in the maternal blood. For this purpose the guinea pig has

been chosen, because its placenta belongs to the same type as the human (hemochorial) and because its period of gestation is long enough to permit separation of different stages of development.

The present research deals with the permeability of the guinea pig's placenta to inorganic phosphorus. Radioactive sodium hydrogen phosphate was used as the tracer substance; it was prepared in the cyclotron of the Department of Terrestrial Magnetism. As usual in such experiments, measured amounts of the tracer substance, of known radioactivity, were injected into the veins of pregnant animals. After appropriate intervals of time the fetuses were delivered by abdominal hysterotomy ("Caesarean section") under anesthesia, and the amount of radioactive substance in them was determined by an electroscopic instrument (pressure ionization chamber connected to a string electrometer). The necessary technical precautions and mathematical calculations are explained in this and previous articles by Dr. Flexner and his colleagues.

The chief conclusions from the experiments are: (1) The rate of transfer of inorganic phosphorus per unit weight of placenta increases about 10 times from the 31st day of pregnancy until term. (2) The placenta is about 10 times as permeable to water as to sodium, and about twice as permeable to inorganic phosphate as to sodium. (3) Unlike sodium and water, which in previous investigations have been found to be supplied to the fetus in amounts much larger than the quantities incorporated in the growing tissues, inorganic phosphate reaches the fetus from the maternal plasma in an amount approximately equal to the total phosphorus retained in growth. The quantity of phosphorus thus retained by the fetuses is large as compared with the amount of inorganic phosphorus in the maternal blood plasma.

A 100-gm. fetus, for instance, retains in each hour 1.5 to 2 mg. of phosphorus, a quantity about equal to all the inorganic phosphorus in its mother's plasma. The implication is that maternal phosphorus stores are essential in the maintenance of growth of the fetus and that these stores may be the organic molecules containing phosphorus, from which the phosphorus is liberated by enzyme activity as needed.

DISTRIBUTION OF WATER IN THE INFANT

Tracer techniques afford the possibility of estimating the proportion of the total water in the body that is extracellular, i.e. in the blood, other body fluids, and extracellular spaces in the tissues, rather than within the cells. The volume of extracellular fluid in adult man has been measured repeatedly by use of sodium tagged with its radioactive isotope. The first such estimate for the newborn human infant has now been reported by Flexner, Wilde, Proctor, Vosburgh, Cowie, and Hellman. The results obtained give essential information for the current studies on the permeability of the human placenta, as well as a sharp, consistent answer to the significant questions: What proportion of the body, by weight, in the newborn is water? and how much of this water is extracellular?

Sodium chloride, tagged by radioactive sodium having an intensity of radiation safely below that known to produce biological effects, was dissolved in water containing deuterium oxide (heavy water). The solution was injected into a vein of the infant. Two and one half to three hours later a sample of blood was drawn from a vein. It is known that such an interval is long enough to permit thorough distribution of the heavy water, that is, to get it into equilibrium between the blood and the water outside the blood vessels. It is also known to be long enough to per-

mit practically complete equilibration of sodium between blood and extravascular water. The deuterium oxide goes everywhere in the body along with the ordinary water; the tagged sodium goes everywhere that ordinary sodium goes, that is to say, into all the extracellular fluid, but not into the cells, which it does not normally enter. As a consequence of this difference, the sodium distributes itself between the blood, on one hand, and the fluid that lies between and about the cells and in the body spaces, on the other hand. The water distributes itself between the blood, on one hand, and all the rest of the body, including the cells, on the other hand. Having thus a larger space to fill, more of it (proportionately) than of the sodium leaves the blood. Thus the blood sample after 3 hours has lost more of the heavy water than of the tagged sodium. The difference tells us what proportion of the water has gone into the cells; and the degree to which the heavy water in the blood becomes diluted with ordinary water, exchanging with it from the tissues, tells how much of the body is water. The calculations are explained by Dr. Flexner and his colleagues in their paper.

The result is that the newborn infant is found to be 74.6 per cent water. This figure, obtained as described from living healthy infants, is almost exactly the same as that found by previous investigators (Iob and Swanson) who desiccated a stillborn infant. Flexner and his colleagues found that the extracellular water in the newborn infant is 43.5 per cent of the body weight. This too agrees well with an estimate (43 per cent) made by Harrison, Darrow, and Yannet by calculation from the chloride content of the stillborn infant. The new observations greatly strengthen available evidence that the process of growth is accompanied by an increase in

the ratio of the intracellular to the extracellular water.

THE ANATOMY OF HARELIP

Dr. Ferdinand C. Lee, of the Johns Hopkins Hospital Surgical Clinic, became interested in the orbicularis oris muscle, which serves as a sphincter of the mouth, because of his experience in several operations for double harelip. Finding that it is important to know how much of the orbicularis oris is present in such cases, he undertook a detailed study of a specimen in the Carnegie Collection (no. 5605), a 5-months-old Negro infant whose body was presented by Dr. Harold Cummins, of Tulane University, because of multiple congenital abnormalities. The deformities of the hand and foot have been described previously by Dr. Streeter. Dr. Lee's description will be of interest in detail to plastic surgeons. In brief, the orbicularis oris muscle in this child with double harelip was found to be well developed at the corners of the mouth but to become thin and fragmentary as the ala of the nose is approached.

ACTION OF DYESTUFFS ON TUMORS

The observations of Dr. Margaret R. Lewis, of the Department's staff, and her coworkers at the Wistar Institute on the effect of the dyestuff Nile blue on sarcomas have been followed by tests of a large series of related dyes. Two dyes of the oxazine series (Nile blue and cresyl violet), twelve xanthine dyes, including acridine red and rhodamine B, and five acridine dyes were found to stain transplanted sarcomas selectively and to retard their growth when administered to the host mice in their diet. All these dyes also stained spontaneous mammary gland adenocarcinomata when fed to tumor-bearing mice.

Studies are under way on the possibility

of modifying these dyes so as to make them more effective in their action on tumors and less toxic for animals.

MICROTOMY

One of the chief problems in the precise sectioning of delicate structures such as human embryos is distortion of the section caused by compression by the knife. Most microtomes abruptly shear the section from the block of paraffin or celloidin (or paraffin-celloidin) in which the specimen is embedded, by pushing the knife edge directly through the matrix. Thus the tissues are compressed in the direction of the cut. Although the error thus introduced may be minimized by proper embedding and by skillful arrangement of the conventional microtome, residual distortion remains a problem even with expert technique. Mr. O. O. Heard, senior modeler of the Department of Embryology, has given a good deal of thought to this problem and has attempted a solution by making the knife slice, rather than push, through the block. To this end he modified an ordinary sliding microtome by fitting it with a circular knife that is made to undergo rotary motion as it passes through the block, thus slicing through the tissues like the familiar rotary meat cutter seen in butcher shops. The knife, however, does not rotate continuously, but stops for manual removal of the section and then reverses its rotary movement as it is returned to the starting point of the microtome track to begin the next cut. The cutting is done with a wet knife, as is usual in this laboratory in sectioning human embryos embedded in paraffin-celloidin.

Mr. Heard had to design and construct not only the knife and the knife-carrier assembly, but also a special machine for sharpening the circular edge, under microscopic observation, to a high precision both

of radius and of cutting edge. The apparatus is fully described in his paper.

The instrument as constructed causes about 40 per cent less compression of the section in the direction of advance of the knife, all other conditions being equal, i.e. embedding media, knife angles, and working temperature. The use of a microtome so unorthodox introduces new problems in

handling the sections, which to some extent counterbalance the reduction of distortion. Whether or not the circular knife ultimately wins general adoption, it is certain that the thoughtful work of Mr. Heard has greatly enriched the knowledge possessed by our staff of the physical and mechanical problems involved in the cutting of thin serial sections.

DIFFUSION AND POPULARIZATION OF RESULTS

Several members of the staff (Burns, Flexner, Corner) each lectured once or twice by invitation to the first-year medical students of Johns Hopkins University. Dr. Burns was asked to discuss his work before the seminar of the Department of Biology of Princeton University. Dr. Reynolds spoke by invitation to the Spring Seminar of the Ciba Corporation, Summit, New Jersey, discussing responses of the uterus to drugs. He also took part in a panel discussion on menstrual disorders, held by the Section on Obstetrics and Gynecology of the American Medical Association at its annual meeting in June 1947. In April Dr. Reynolds addressed a large meeting of the (Negro) Women's Cooperative League, in connection with National Negro Health Week, speaking on problems of the menopause.

Dr. Flexner gave the Director valuable assistance in arranging a Symposium of the National Academy of Sciences on radio-

active tracers, and took part himself. Dr. Corner served during the year on the committee that organized a series of scientific broadcasts in the intermission of the Sunday afternoon concerts of the New York Philharmonic Orchestra. On April 13 he gave the concluding talk of the series, "Light on the blood capillaries."

Arrangements have been made by which the motion picture films on cell growth, segmentation of the egg, and tumor cells made by Dr. Warren H. Lewis prior to his retirement in 1940 are to be made available for distribution by the American Cancer Society. The Department of Embryology will retain title to the negatives, leaving them in the care of Dr. Lewis, who will supervise the editing of the films and the preparation of duplicate negatives from which prints will be made for distribution. A set of prints of all the films thus far edited from negatives made in this laboratory has been deposited with us.

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DEPARTMENT OF GENETICS

Cold Spring Harbor, Long Island, New York

M. DEMEREC, *Director*

In many ways the year 1946-1947 was very different from any we have experienced in recent times. In comparison with the early postwar period, a definite improvement was evident in respect to the accessibility of scientific instruments, laboratory equipment, and chemicals. Some improvement was noticeable also in the obtainability of materials needed for the upkeep of our plant, but many essential items were still hard to procure. During this year our Department received two grants: one from the United States Public Health Service, for Kaufmann's research dealing with the nature of the changes induced in the living cell by irradiation; and the other from the American Cancer Society, for studies of the mutagenic capacities of carcinogens.

An expansion in research activities in general, brought about by the influx of new funds, has accentuated the shortage of scientific personnel. We have felt this shortage particularly as it relates to specialized workers eligible for fellowship appointments. Fortunately, we have not yet experienced any difficulty in filling research assistantships.

The research activities of the Department are making satisfactory progress toward the goals set by our program. In McClintock's work on maize, a number of mutable loci have appeared during the past few years in the cultures grown to determine the factors involved in a particular but unrelated type of mutation process. Preliminary investigations of some of these mutable loci indicated that a common underlying phenomenon was probably associated with the expression of

instability in all the cases examined. Two separable factors are known to be associated with the expression of instability. The first factor is concerned with the particular state of the unstable locus in cells of a developing tissue. The state of a locus is reflected by the time of occurrence of phenotypically visible mutations and by the frequency and distribution of these mutations. During development, the state of a locus may change abruptly. The second factor is concerned with a change at the unstable locus that gives rise to a phenotypically recognizable altered expression of the locus. Both the changes in state and the change that alters the action of a locus appear to be associated with events that occur during a mitotic cycle. During the past year Dr. McClintock's attention has been concentrated on one of these mutable loci because its actions and its location in the chromosomal complement are particularly favorable for an analysis of the factors associated with mutability. Instability of this locus occurs only when an independently inherited dominant factor is likewise present in the nucleus. When this dominant factor is removed from the chromosome complement by appropriate crosses, the mutability of the unstable locus is completely suppressed. When the dominant activator is reintroduced into the nucleus by appropriate crosses, instability of the locus reappears. Mutations at the particular locus may be followed in all tissues throughout the life cycle of the plant. In the sporophytic tissues mutations occur only late in development. In the endosperm, on the contrary, mutations may occur at all stages in de-

velopment. Changes in state of the unstable locus, however, may occur at any time during the development of either the endosperm or the sporophytic tissues. Although changes in state of a locus and the subsequent changes in frequency and distribution of visible mutations are interrelated, the alteration that is associated with a change in state and the alteration that results in a phenotypically visible mutation are distinct and separable. Because the action of the unstable locus chosen for intensive study lends itself to cytological as well as genetic analyses, efforts are being concentrated on the visible chromosomal alterations that accompany mutations at the unstable locus.

McClintock interrupted her studies of the mutable loci in maize during the fall and early winter of 1946 in order to continue, at the California Institute of Technology, the investigations of the chromosomes of *Neurospora* begun several years earlier. There were two primary objectives for this interim study: (1) to improve the techniques so that chromosome conditions in the important stages might be more readily revealed, and (2) to obtain a set of photographic illustrations of the behavior of the chromosomes during ascosporeogenesis. These primary objectives were accomplished. In addition, a more detailed and complete knowledge of chromosome organization and behavior was obtained.

In an extension of the series of studies utilizing near infrared radiation, Kaufmann has found that this agent, which previously had been shown to increase the frequency of X-ray-induced chromosomal rearrangements in *Drosophila melanogaster*, does not modify the frequency of X-ray-induced recessive lethal mutations in this species. Since about 35 per cent of these lethals were found to be associated with chromosomal rearrangements, it seems clear that lethals of this type are not

caused by a position effect and do not depend on the production of the rearrangement for their origin and expression. From a consideration of the extensive data that he has now collected, Kaufmann has concluded that near infrared radiation acts as a "sensitizing" agent in increasing the frequency of X-ray-induced chromosomal rearrangements by facilitating recombination, probably at the expense of restitution, among the group of potential breaks induced by the ionizing radiation. The precise definition of the time of action of near infrared radiation emphasizes the potentialities of this agent as a tool in experiments designed to modify the recombination aspect of the process of induced structural change.

Working in Kaufmann's laboratory during the summer of 1947, Marcia Kelman Iddles has extended the series of observations on the extent of nonhomologous association among the discs of the salivary-gland chromosomes of *D. melanogaster*. About 350 cases of this type of association have now been observed in a study that is furnishing information concerning the distribution of heterochromatic and duplicated euchromatic regions along the various chromosomes of this species.

McDonald has continued her efforts to perfect methods for the preparation of purified crystalline enzymes. She was successful in devising a method for the preparation of ribonuclease—an enzyme capable of depolymerizing ribonucleic acid but not desoxyribonucleic acid—free from all measurable traces of proteolytic activity. By using this enzyme in cytochemical studies, Kaufmann has been able to show that the chromosomes, as well as the nucleolus and cytoplasm, contain measurable quantities of ribonucleic acid. Kaufmann and McDonald, with the assistance of Miss Helen Gay, whose services have been provided by a grant from the United States Public

Health Service, have also succeeded in developing a test for the *in situ* localization of tryptophane-containing proteins.

MacDowell has confirmed earlier indications of a mother's-age factor in mice that strongly modifies the incidence of spontaneous leukemia in hybrids from non-leukemic mothers. Young mothers give many leukemics, old mothers few. For a new experiment to test the possible transmission of this inhibiting factor through mother's milk, the four classes of young from old and young mothers divided between young and old nurses have been born, nursed, and weaned. A filterable, virus-like agent of mild pathogenicity has been separated from the leukemic cells of line-I leukemia, with which it has probably been long associated.

Within the past two years methods have been developed by Demerec and his collaborators for studying the mutagenic properties of chemicals, using *Drosophila* and bacteria. During the summer of 1947 a general survey was made of the genetic effectiveness of carcinogens, which are suspected by geneticists of being mutagenic. Extensive experiments carried on by Demerec with aerosols of a number of carcinogens and chemically related substances have shown that mutations may be induced by some of these in *Drosophila* males. A considerable degree of correlation was observed between mutagenic and carcinogenic capacities, indicating a common causative relation between the two. The most obvious and probable relation between mutagenicity and carcinogenicity is the one suggested by the hypothesis that cancer may originate through a gene mutation occurring in a somatic cell.

Newcombe has made a detailed investigation of the spontaneous mutation rate in bacteria. He found that when resting bacteria are used to begin an experiment the

mutation rate is high during the first few divisions, as compared with later divisions.

Beale perfected the method devised two years ago (Year Book No. 44, p. 115, 1945) for studying the mutation rate in dividing bacteria. He was able to follow the mutation rate during about twelve bacterial generations. For mutation from B (bacteria sensitive to phage) to B/1 (bacteria resistant to phage T₁), the rate is 7×10^{-9} per bacterial division.

It was previously known that in the gall midges (Diptera, Cecidomyidae) the nuclei of the germ-line cells (primordial germ cells, oögonia, spermatogonia) contain far more chromosomes than the somatic cells, and it was assumed that the germ-line cells were polyploid (octoploid, decaploid, etc., according to the species). An investigation made by White of a species of cecidomyid which is a pest of box hedges has shown that this assumption is untrue; and it now appears that there are two kinds of chromosomes in cecidomyids—those that are confined to the germ line and those that occur both in the soma and in the germ line. The former are eliminated from the future somatic nuclei at one of the early cleavage divisions. Dr. White has studied the mechanism of this elimination in the species mentioned above. He has also carried out work on the salivary-gland chromosomes of a number of species of gall midges.

Professor Th. Dobzhansky, of Columbia University, research associate of the Carnegie Institution, has studied the dynamics of changes occurring in *Drosophila pseudoobscura* by investigating natural populations of the fly in localities near the gardens of the Division of Plant Biology of the Carnegie Institution at Mather, California, and also by observing the behavior of mixtures of various types under controlled conditions in the laboratory, where flies

are raised in specially constructed "population cages." He has found that the proportion of certain types in wild populations changes with the season. Similar changes are observed under laboratory conditions when the temperature is varied. Since these changes are extremely rapid, the differences in the adaptive values between various types must be very great. Professor Sewall Wright, of the University of Chicago, has computed that, taking the adaptive value of heterozygotes to be 1.0, the adaptive value of one homozygote is about 0.7, and that of another homozygote as low as 0.4. The finding of such large differentials among normal constituents of a natural population is most unexpected, since it has customarily been assumed in modern biology that the intensities of natural selection operative in nature are, except for abnormalities and pathological conditions, very low. The material accumulated by Dobzhansky on *Drosophila* is sufficiently extensive to be compared with material obtained by Clausen, Keck, and Hiesey, of the Division of Plant Biology, in their work on the local races of some plant species. It is of interest to note that the fly *Drosophila pseudoobscura* exhibits essentially the same kind of differentiation into altitudinal races that has been observed by them for certain plants.

It is well known that mutations that arise in the laboratory are mostly deleterious, or at best neutral, to the viability of their carriers. This seems to contradict the view, now held by most biologists, that the mutation process supplies the raw materials of evolution. The apparent contradiction is usually resolved by supposing that some mutations, although harmful in a normal environment and in combination with genes normally present in the species, may be useful in other environments and in combination with other genes. Dobzhansky has obtained evidence in support

of this view by conducting specially designed experiments with *Drosophila*.

During the year several changes in scientific personnel have occurred. Dr. S. G. Stephens, who had held the position of research associate since June 1, 1945, left the Department in December 1946 to collect cotton in Mexico and Central America for the Empire Cotton Growing Corporation and the United States Department of Agriculture. At present he is continuing research on the cytogenetics of cotton at the Department of Agronomy, Texas Agricultural Experiment Station. Professor Michael J. D. White, of the University of London, stayed with us as a guest investigator from April through August 1947. Dr. Evelyn M. Witkin held a fellowship of the American Cancer Society.

With the return of peacetime activity, the benefits to be derived from our cooperation with the Biological Laboratory of the Long Island Biological Association are increasing. The 1947 summer symposium on "Nucleic Acids and Nucleoproteins" brought to Cold Spring Harbor a distinguished group of scientists interested in the problems being investigated by members of our Department, and provided opportunities for our staff to discuss their work with them. Of the approximately 150 participants, seven had come from Europe for the purpose of attending the meeting. These were Professor and Mrs. Edgar Stedman from Edinburgh, Professor J. N. Davidson from London, Professor J. M. Gulland from Nottingham, Drs. H. Hydén and B. Thorell from Stockholm, and Professor André Boivin from Strasbourg. Three years ago, as part of the summer activities of the Biological Laboratory, a course was organized by Dr. M. Delbrück on methods used in studies with bacteriophages. This course, which has been offered each year since

then, is designed primarily for research workers who either expect to work with phages or wish to obtain a better understanding of the problems involved in such research. It attracts particularly those scientists who are interested in the borderline fields of biology, physics, and chemistry. This year the course was given by Professor Mark Adams, of New York Uni-

versity. It brought to Cold Spring Harbor, among others, the nuclear physicists Drs. Leo Szilard and Aaron Novick, from the University of Chicago, P. Morrison, from Cornell University, and R. B. Roberts, from the Department of Terrestrial Magnetism of the Carnegie Institution, with whom we were glad to discuss our problems.

THE GENE

M. DEMEREC, E. M. WITKIN, H. B. NEWCOMBE, AND G. H. BEALE

The principal object of our group during the past year has been the study of spontaneous and induced mutability in bacteria (*Escherichia coli*) and in *Drosophila*. Using methods previously worked out, an effort was made to determine the mutagenic properties of various chemicals. In this work we were assisted by Misses M. N. Crippen, Nancy McCormick, and Jessie Flint, Mrs. Jennie Buchanan, and Mr. John Derby, and during the summer months by Mr. W. E. Baty, science teacher at the Huntington High School, Misses Margaret Lieb, Patricia St. Lawrence, Dorothy Wei, and Reba Mirsky, and Mr. Clifford Tengelsen.

MUTAGENIC POTENCY OF CARCINOGENS AND CHEMICALLY RELATED COMPOUNDS

During the past two years M. Demerec has developed an aerosol method for the treatment of *Drosophila* males with solutions of various chemicals. This method was considerably improved during the summer of 1947 by the introduction of various technical refinements. At present, air pressure is generated by an electric air pump, and a constant air flow of approximately 6 liters per minute is passed into a DeVilbiss glass nebulizer, no. 40, containing about 5 ml. of the solution to be used in treatment. The nebulizer generates

the aerosol, which is piped through plastic tubing into a half-pint milk bottle, where the large droplets occasionally thrown out by the nebulizer are retained. From this bottle the aerosol is piped into a similar bottle containing fly food and the flies to be treated. Excess aerosol is carried from the bottle containing the flies through another tubing into the air; or, if the chemical being used in treatment is toxic, the excess aerosol is passed through activated charcoal before being discharged into the exhaust. Aerosol generation is started by turning on the pump. Treatments are usually of long duration—up to 200 hours or longer, depending on the toxicity of the chemical used. As a rule, flies are kept in the same bottle throughout treatment, but the bottle is changed if it becomes too moist or sticky. The aerosol is generated periodically, every 30 minutes for 30 seconds. Since this is regulated by an electric time switch, treatment can be carried on without any attention except for occasional examination of the flies to make certain that they are surviving the treatment. By means of this system, flies are kept in an atmosphere containing an aerosol of a chemical solution, and this atmosphere is renewed every 30 minutes. Since a majority of the aerosol droplets have a diameter of 1.5 microns or less, they are able to penetrate into the tracheae of the heavily

tracheated testes, and thus the chemical used in treatment may reach the sperm present there.

Sperm from treated males was tested for possible genetic changes by the usual methods. For determining the frequency of gene changes, observations were made on X-chromosome lethals. In the early experiments, the *CIB* method was used, but in all the more recent work Muller's double-inversion stock *sc⁸ w^a B* was utilized. The advantage of using this stock is that cultures containing only a few flies as well as those containing lethals can be tested with ease through another generation. Because of the difficulties involved in such tests when *CIB* is used, cultures having a few flies are disregarded, and since they contain a larger proportion of lethals than other cultures this tends to lower the frequency of lethals shown in the final results.

In the early part of the work, which was begun in June 1945 (Year Book No. 39, pp. 215-216; No. 45, pp. 156-157), several reducing and oxidizing chemicals, as well as dyes, were tested, but no evidence of mutagenic effect was obtained. At that time the maximum length of exposure was 16 hours, and so it is not certain that a longer period of treatment might not have been effective in some cases. Positive evidence that the aerosol method was effective in inducing mutations was obtained when nitrogen mustard—methylbis(betachloroethyl)amine—was used. The work of Auerbach and Robson, of the University of Edinburgh, had shown that mutations may be induced in the sperm of *Drosophila* males by exposure to vapors of either mustard gas or nitrogen mustard. Therefore it was reasonable to expect that an aqueous aerosol of nitrogen mustard would be effective. Our experiment was made as soon as the chemical became available to us, shortly after the end of the

war. As already reported (Year Book No. 45, pp. 156-157), it gave positive results.

Since the work began we had been planning to test the mutagenic capacity of carcinogens; but we were hesitant to start work with aerosols of such potentially dangerous chemicals until we were certain that our method was effective. In 1940 we had made an attempt, in co-operation with Dr. A. Hollaender, of the National Institute of Health, to induce mutations in *Drosophila* by raising them for 12 generations on food containing dibenzanthracene, and also by treating the flies so obtained with ultraviolet radiation. Both experiments gave inconclusive results. When proof of the effectiveness of the aerosol method was obtained, experiments with 1,2,5,6-dibenzanthracene were undertaken. As indicated in table 1, these gave positive results (*Nature*, vol. 159, p. 604, 1947).

With the aid of a grant from the American Cancer Society, the research to test the mutagenic potencies of carcinogens was considerably extended, beginning in July 1947. During the summer, tests were carried on with 21 carcinogens and related chemicals. These tests covered: (1) induction of mutations (lethals) in the X chromosome; (2) location of mutations along the chromosome, in order to discover possible specific effects; (3) detection of chromosome rearrangements coincidental with mutations, and cytological analysis of such rearrangements; and (4) detection of translocations involving any two of the four chromosomes, with cytological analysis of such translocations. These experiments are still in progress, so that only a preliminary report will be given here. The tests concerned with induction of mutations have progressed farthest, and some of the data obtained in these experiments are given in table 1. Experiments with 17

chemicals have advanced far enough so that these chemicals may be classified into four groups so far as mutagenic capacity is concerned: (1) positive; (2) probable, where the results so far are positive, but tests have not yet been carried through the third generation; (3) questionable, where results indicate a slight effect, and additional experiments are needed before a conclusion is reached; and (4) negative,

along the X chromosome, indicating that the mutagens responsible for these mutations are not specific, but affect genes at random.

An examination of table 2 shows that three potent polycyclic hydrocarbon carcinogens—namely, dibenzanthracene, methylcholanthrene, and benzpyrene—are also positive mutagens. Of the four chemically related noncarcinogens, pyrene

TABLE 1

SUMMARY OF DATA ON X CHROMOSOME MUTATIONS (LETHALS) OBTAINED FROM MALES TREATED WITH SEVERAL CARCINOGENS

TREATMENT	NO. SPERM TESTED	MUTATIONS		DIFFERENCE	D/S E
		No.	% \pm S.E.		
Control					
none	1342	2			
sesame oil	2540	7			
total	3882	9	0.23 ± 0.077		
Positive					
1,2,5,6 dibenzanthracene	3257	31	0.95 ± 0.17	0.72 ± 0.19	3.8
methylcholanthrene	3727	24	0.64 ± 0.13	0.41 ± 0.15	2.7
benzpyrene	4299	25	0.58 ± 0.12	0.35 ± 0.14	2.5
sodium desoxycholate	2561	26	1.02 ± 0.20	0.79 ± 0.21	3.8
p hydroxyazobenzene	2416	15	0.62 ± 0.16	0.39 ± 0.18	2.2
Negative					
alpha naphthylamine	2591	5	0.19 ± 0.086		
p diethylaminobenzene	1690	2	0.12 ± 0.084		
p-dimethylaminobenzene	3219	8	0.25 ± 0.088		
pyrene	1172	3	0.26 ± 0.15		

where the data now available do not show any effect. See table 2.

Up to now, chromosome aberrations have been detected only in experiments with dibenzanthracene and benzpyrene. Three cases of inversion (one consisting of two inversions in the same chromosome) have been found among 28 chromosomes carrying lethals induced by dibenzanthracene, and one inversion has been observed among 15 lethals from benzpyrene.

In the materials tested, induced mutations have been distributed at random

and phenanthrene are not mutagenic, and anthracene and benzanthracene are in the questionable class, that is, they are either nonmutagenic or slightly mutagenic. For the tested chemicals of this group, therefore, the correlation between mutagenicity and carcinogenicity may be considered very good.

A carcinogenic member of the naphthylamine group (beta) has questionable mutagenic potency, and a noncarcinogenic member (alpha) is nonmutagenic. In this case the mutagenic potency of beta (as

tested with *Drosophila*), if present at all, is not so high as its carcinogenic potency.

Of the six azo compounds tested, two are mutagenic, two are probable, and two are negative. In this group three noncarcinogens are either mutagens or probable mutagens, whereas only one carcinogen (*p*-dimethylaminoazobenzene) has

TABLE 2

LIST OF CARCINOGENS AND RELATED CHEMICALS ARRANGED ACCORDING TO MUTAGENIC CAPACITY, AS DETECTED IN *DROSOPHILA*

Positive mutagens:	Carcinogenic
1,2,5,6-dibenzanthracene	yes
20-methylcholanthrene	yes
3,4-benzpyrene	yes
<i>p</i> -hydroxyazobenzene	yes
sodium desoxycholate	not tested
<i>p</i> -aminoazobenzene	no
Probable mutagens:	
azoxybenzene	no
azobenzene	no
Questionable mutagens:	
anthracene	no
1,2-benzanthracene	no
beta-naphthylamine	yes
Negative:	
alpha-naphthylamine	no
pyrene	no
phenanthrene	no
<i>p</i> -diethylaminoazobenzene	no
<i>p</i> -diethylaminoazobenzene	yes
acetylaminofluorine	yes

not shown mutagenic potency. This is being tested further with a higher concentration. It is evident that among the azo-group compounds used in our tests a larger proportion shows mutagenicity than carcinogenicity.

The experimental results can be seen in better perspective if the conditions under which the effect was produced are kept in mind. Presumably the aerosol droplets enter with air through the spiracles of a fly, and are distributed within the body

through the tracheae and tracheoles. Since the testes are well supplied with tracheoles, a considerable amount of the aerosol must reach them. In order, however, that an aerosolized chemical may reach the sperm and induce a genetic change there, it must pass through the tracheolar cells, the hemolymph, and the cells constituting the membrane of the testes. Any obstruction or failure at any point along this path would reduce the effectiveness of the chemical or suppress it entirely. Consequently, failure to obtain positive results after treatment with a certain chemical does not necessarily mean that this chemical is not mutagenic; it may mean that it is not able to enter any of the several cells which it has to pass through before reaching the sperm, that it is not able to pass through these cells in sufficient quantity, or that it is not able to penetrate into a sperm once it is reached. It is also to be expected that permeability for different chemicals may vary with the tissues or that it may be different in different species. A similar set of conditions probably has to be met when mammals are treated with carcinogens.

The results of our experiments show that a majority of the carcinogens tested are mutagenic, and also that a majority of the chemically related noncarcinogens are not mutagenic. Nonmutagenic carcinogens and mutagenic noncarcinogens were observed as well. Nevertheless, considering the important role played by biological factors in the expression of both mutagenicity and carcinogenicity, and considering the biological differences between the materials in which these two effects were studied (*Drosophila* and mammals), the observed correlation between the two effects appears to be quite striking. From this correlation it seems unavoidable to infer a common causative relation. This inference is further strengthened by the behavior of all known nonchemical carcinogens, such as X-rays

and related radiations, ultraviolet rays, and heat, all of which are mutagenic. The most obvious and most probable relation between mutagenicity and carcinogenicity is the one suggested by the hypothesis that cancer may originate through a gene mutation occurring in a somatic cell. Such a cell and the cells derived from it by division would have their properties changed so that they would behave as cancerous. This would mean that higher organisms possess a gene—or, more likely, a number of genes—whose mutations can initiate a cancer-type cell. Such mutations, in common with a great majority of mutations in other genes, occur spontaneously with a very low frequency. The human body has a tremendously large number of cells, however, so that it becomes probable that a cancer-type mutation will occur a number of times among the cells of an individual. Not all of these need give rise to cancer, since a large proportion of the cancer-type cells may be prevented by normal cells from dividing, or may be eliminated in some other way. This hypothesis readily explains the observed differences between various cancers, as being due to mutations in different genes. If a gene mutation is responsible for the origin of cancer, then all mutagenic agents would be expected to increase the frequency with which such mutations occur and consequently to behave as carcinogens. In our fight against cancer, therefore, precautions should be taken to avoid exposure to all mutagens—chemicals as well as radiations. Such precautions, however, even if rigorously enforced, would only lower the incidence of cancer; they could not entirely prevent its occurrence. There would still be a chance left for cancer-type mutations to occur among the billions of cells that constitute the human body, and if such a mutated cell should continue to divide it would give rise to cancerous growth. We know that

mutations do occur with great regularity, caused by some force as yet unexplained, and that we have no means of stopping or controlling their occurrence. Consequently, if cancer originates through a genetic change, our chances for finding ways to prevent it are very, very slight. We should be able to reduce its frequency by avoiding contact with carcinogenic and mutagenic agents. In this effort a more extensive knowledge of the mutagenic capacities of various substances should be a valuable asset.

INDUCTION OF MUTATIONS IN BACTERIA BY CHEMICALS

Early in 1947, Dr. Evelyn M. Witkin, fellow of the American Cancer Society, began work on the induction of mutations by chemicals in *Escherichia coli*. Demerec had described experiments (see Year Book No. 44, p. 115) in which mutations in *E. coli* from sensitivity to resistance to bacteriophage T₁ were induced by ultraviolet radiation and X-rays. It was reported that some of these mutations express themselves before the bacteria pass through the first division after irradiation (zero-point mutations). In the investigation of the mutagenic activity of chemicals, zero-point mutations to resistance to bacteriophage T₁ were used as the genetic index of positive or negative effects.

Strain B/r of *E. coli*, the strain used in the experiments of Demerec, was employed throughout. It was established first of all that bacteria from full-grown cultures of this strain, washed free of nutrient medium and resuspended in distilled water, undergo no changes, over a period of 48 hours of incubation at 37° C., in the number of viable cells and in the number of mutants resistant to bacteriophage T₁ (B/r/1). Thus, under these conditions there is no division or death of the bacteria, and no

spontaneous mutations to phage resistance occur. A given chemical was tested for mutagenic activity by the following procedure: The concentration of the chemical required to kill about 99 per cent of the bacteria suspended in it in a standard time period (usually 2 or 3 hours) was determined in preliminary toxicity tests. A full-grown culture of strain B/r was divided into two equal parts, and each portion was centrifuged to eliminate the nutrient medium. The bacterial pellet of one portion was resuspended in distilled water to serve as a control. The other was resuspended in the concentration of the chemical known to kill 99 per cent of the exposed bacteria in the standard time period. The two tubes were incubated at 37° C. for this period of time, and were then assayed to determine the number of living bacteria per milliliter and the number of B/r/1 mutants in a series of carefully measured samples. It was then possible to compare the number of B/r/1 mutants per 10⁸ living bacteria in the control with the number per 10⁸ survivors in the treated culture. When the number of B/r/1 mutants per 10⁸ living bacteria was found to be significantly higher in the treated culture than in the control, experiments were conducted to determine whether selection might be responsible for this result. It was concluded that zero-point mutations were induced by a given chemical if the following conditions were met: (1) the proportion of B/r/1 mutants among the survivors of treated cultures was significantly higher than in controls; (2) selection in favor of the mutants could be ruled out as responsible for this increase; and (3) the mutants isolated from the treated cultures proved to be stable, bona fide B/r/1 mutants.

Four compounds have been tested for mutagenic activity by the procedure outlined above. These substances, the first of

a series to be investigated in an extensive survey, were selected because of their more or less well defined physical or chemical effects upon nucleoproteins or nucleic acids.

Sodium desoxycholate, which is known to dissolve the desoxyribose nucleoprotein complex of bacteria and animal tissues, was found to be effective as a mutagenic agent. In a typical experiment, the proportion of mutants among the survivors of a 3-hour exposure to a 5 per cent solution of desoxycholate was 58 per 10⁸ bacteria, as compared with 3 per 10⁸ bacteria in the controls. The sensitivity of B/r/1 mutants to the toxic action of the chemical was the same as that of the nonmutants, so that selection could not be responsible for this increase. The mutants obtained after treatment with desoxycholate were stable and typical B/r/1 mutants. The possibility that the chemical might interfere with the process of infection by T₁, thus permitting the sensitive survivors of the treatment to divide before lysis and give rise to new mutants spontaneously, was carefully investigated. It was found that desoxycholate-treated bacteria are infected by bacteriophage at least as rapidly as untreated bacteria from the same culture. Thus, interference with the action of the bacteriophage was eliminated as a possible explanation of the heightened proportion of mutants among the survivors.

The number of induced mutations per 10⁸ survivors was found to be directly proportional to the time of exposure to a 5 per cent solution of sodium desoxycholate. A similar linear relation was reported by Demerec and Latarjet between the number of induced zero-point mutations and the X-ray dose. A comparison of the curves obtained for X-rays and sodium desoxycholate reveals that a dose of 100,000 roentgen units corresponds to an 8-hour exposure to 5 per cent desoxycholate, in

that about 110 mutations per 10^8 survivors are induced under each of these conditions.

Of the other compounds tested, pyronin Y and acriflavine, both of which are dyes known to combine with nucleic acids, showed positive mutagenic effects. Methyl green, another basic dye, was clearly non-mutagenic within the limits of the experimental technique.

It is hoped that this method can be developed as a rapid screening procedure for detecting mutagenic activity among various chemical groups, and as a tool for investigating certain aspects of chemically induced mutations, such as dosage-effect relations and delayed effects.

POSSIBLE DELAYED EFFECT IN SPONTANEOUS MUTATIONS

Rates of mutation to phage resistance in *Escherichia coli* have in the past been obtained in two ways: (1) by calculating from the proportion of small cultures having no mutants, and (2) by calculating from the average number of mutants per culture. These have yielded figures differing by a factor of from 2 to 5 in the different mutations studied, the latter method giving the higher estimate in all cases (Demerec and Fano, 1945). Such a difference could result from a high mutation rate during the period of rapid growth, or from a delay between the occurrence of the gene change and its phenotypic expression in the descendants of the original genetic mutant.

To discriminate between these two alternative possibilities, Dr. H. B. Newcombe has made a study of mutation rate in relation to the stage in the growth of the bacteria. The method used was essentially that employed earlier for investigating mutation in irradiated material (Demerec, 1946). Bacteria were grown on agar and, after varying periods of incuba-

tion, sprayed with the phage T1. By this process all bacteria susceptible to T1 are eliminated and any clones of resistant bacteria survive to form colonies on further incubation. Thus mutations are detected as units, regardless of the numbers of individuals that have descended from them. To determine the extent of growth, plates incubated at the same time and for the same period were washed with saline and the resulting suspensions assayed.

From these experiments it was found that clones of mutants appeared at a high rate during early growth (12.0 per 10^4 bacterial divisions during the first generation on agar) and that the rate declined, after approximately four divisions, to 0.74 per 10^8 bacterial divisions. This latter figure is approximately that obtained previously (Demerec and Fano, 1945) from the proportion of cultures having no mutants.

If the high mutation rate obtained from the average number of mutants per culture (2.7 per 10^8 bacterial divisions) were due to a high rate during the period of rapid growth, then one would not expect the rate as determined from the appearance of resistant clones on agar to drop to 0.74 per 10^8 until after a considerable period of growth. It may therefore be assumed that there is a delay in the phenotypic expression of the genetic change determining phage resistance.

On this basis the rate of genetic change would be greater than the rate of appearance of resistant clones by a factor of 2^n , where n is the number of generations between mutation and phenotypic change, regardless of whether the character was expressed in all 2^n descendants simultaneously or in only one.

To obtain a better estimate of mutation rate from liquid cultures, and to avoid the statistical fluctuations inherent in the method using series of small cultures started from small inocula, the increase in

resistant bacteria in cultures from large inocula was studied. In such cultures, grown for a period of approximately six to seven generations, the estimated mutation rate was $4.1 \text{ per } 10^8$ bacterial divisions. The fact that this is larger than the figure obtained from cultures started from small inocula has been tentatively ascribed to the carry-over in the inoculum, when it is large, of a certain number of "hidden" mutants which have not yet achieved phenotypic resistance.

Assuming a delay, this is still a minimum estimate of the actual rate of gene change, since it does not take into account the number of "hidden" mutants present at the end of growth. An attempt was therefore made to estimate mutation rate from clones of mutants known to be relatively old, in the belief that a greater proportion of the genetic mutants would have acquired phenotypic resistance. Using the data of Demerec and Fano, and calculating only from the culture in each series having the highest number of resistant bacteria, an estimated rate of $6.3 \text{ per } 10^8$ was obtained. Whether or not all the descendants of early mutations in these cultures had become phenotypically resistant is not known, and upon this depends whether the figure $6.3 \text{ per } 10^8$ is to be considered an approximation to the rate of gene change or whether it is again an underestimate. If the delay is of the order of that observed in irradiated material, as it may well be, then the true rate of gene change would be many times this figure.

The high mutation rate ($12.0 \text{ per } 10^8$) observed during the first division on agar is less easy to interpret. The distribution over the plate of mutants that were not yet phenotypically resistant would not be expected to give rise to a rate higher than that observed in liquid cultures, namely, $4.1 \text{ per } 10^8$. The difference might be in-

terpreted as due to a genuine increase in the mutation rate during this division, to a failure of the bacteria in the early stages of growth to adsorb phage, or to a physiological state favoring phenotypic expression of genetic resistance. Of these possibilities, an increase in the rate of gene change during the first division presumably would not—in view of the delay postulated—be detected until some time later; and the failure to adsorb phage seems unlikely, since it would have to be a matter of complete failure over a period of two full generations. It is tentatively suggested, therefore, that a greater than normal proportion of "hidden mutants" becomes phenotypically resistant during this division.

MEASUREMENT OF SPONTANEOUS MUTATION RATE

In 1943 Luria and Delbrück made a study of the rate of occurrence in bacteria of mutations from phage sensitivity to phage resistance. These workers adopted the technique of growing cultures of *Escherichia coli* in liquid broth medium for given periods of time and subsequently plating out known small amounts of the culture onto nutrient agar, together with an excess of phage. After further incubation the number of resistant colonies on each plate was counted, and estimates of the mutation rate were made from (a) the percentage of cultures that did not contain any resistant mutants at all, and (b) the average number of resistant bacteria per culture. Demerec (1946) modified this method by growing bacteria on nutrient agar instead of in broth, and by applying the phage as a fine aerosol, which was sprayed onto the plates at a time when the bacteria had increased to approximately the desired number. The advantage of this method was that clones of mutants

remained collected together and, after spraying with phage, could be counted as single mutations. The problem then was to determine accurately the number of bacteria on a plate at the time when the phage was applied.

This has now been investigated by Dr. G. H. Beale. Growth of bacteria on nutrient agar was measured by flooding the plates with dilute saline, scraping the bacteria from the agar with a glass spreader, and assaying the supernatant solution thus obtained. It was found that the growth rate on nutrient agar is practically identical with that in broth, and that the initial lag period is also the same. As regards the stage at which growth rate on nutrient agar slows down, it was found that this is determined by two conditions: (1) the absolute number of bacteria on a plate, and (2) the size of individual colonies. Division slows down when the total number of bacteria on a plate exceeds 10^{10} or when the number per colony exceeds 5×10^5 (i.e., the number produced from a single bacterium by 19 divisions). It was also found that if bacteria are taken from a fresh, unsaturated culture of titer 10^7 bacteria per cubic centimeter or less (which may be chilled for 30 minutes), and plated onto nutrient agar that has been preheated to 37°C ., growth starts immediately without any initial lag phase at all. Thus, by using bacteria from an unsaturated culture, and by determining beforehand the growth rate on nutrient agar by the washing technique, it is possible to estimate the number of bacteria on a plate accurately, simply from a knowledge of the number plated and the time of incubation.

Making use of this knowledge, nutrient-agar cultures were prepared, containing about 10^9 actively dividing bacteria. After growth had been checked by chilling, approximately 10^{10} phage particles were

sprayed onto each plate, and after a further incubation period of 48 hours the numbers of phage-resistant colonies were counted. The mutation rate was calculated simply by dividing the mean number of mutant clones per plate by the total number of bacteria per plate (the number of mutants originally present on each plate before growth being zero, and the total number of bacteria originally present being negligible in comparison with the final number). By this method it was found that the mutation rate, expressed as the number of phage-resistant bacteria per cell division, was 0.7×10^{-6} , and this figure did not vary significantly whether the rate was measured after 12 bacterial generations on a plate or after 18 generations. It was therefore concluded that, provided the bacteria are in an actively dividing condition, the mutation rate is a constant function of the number of cell divisions.

Further work has shown, however, that the mutations measured in these experiments constitute a composite group. It had already been known that there are two kinds of mutants resistant to the phage T1—namely, B/1 and B/1,5—and also that the phage T1 produces a mutant T1*h* capable of lysing B/1 mutants. Cross-resistance tests have now shown that a proportion of the B/1 mutants are however resistant to T1*h*, and that a proportion of the B/1,5 mutants are sensitive to T1*h*. Consequently each of the mutants B/1 and B/1,5 exists in at least two forms. Furthermore, the relative proportions of B/1 and B/1,5 mutants have been found to vary (from 1 per cent to 25 per cent B/1) in different experiments, depending on the strains of bacteria and T1 phages used. It is therefore clear that the over-all constancy of mutation rate can only be guaranteed with one particular culture of *E. coli* and one experimental culture of the phage T1.

ORGANIZATION OF THE CHROMOSOME

B. P. KAUFMANN, M. R. McDONALD, H. GAY, K. WILSON, AND R. WYMAN

During the past year our studies of the structure of the chromosome have proceeded in general along the broad lines indicated in Year Book No. 45. Analysis of the modifying effect of near infrared radiation on X-ray-induced lethal mutations in *Drosophila* has now been completed, and a series of experiments has been undertaken to measure the effect of this agent on the frequency of chromosomal aberrations induced by a nitrogen mustard compound. Progress has been made in developing techniques for the direct observation of the effects of ionizing radiations on living cells; other cytological observations have extended our knowledge of the specific patterns of nonhomologous pairing between the discs of the salivary-gland chromosomes of *D. melanogaster*. The chemical and histochemical studies for localization of chromosomal constituents have advanced despite the necessity of surmounting innumerable technical difficulties, and have enabled us to plot in a rough way the distribution within the cell of different types of proteins and nucleic acids. Close co-operation between biochemist and cytologist has facilitated the progress of the work and enabled us to co-ordinate the chemical and histochemical approaches to the problems in hand. Our general program has also been furthered by a grant from the United States Public Health Service, which has provided us with an additional scientific investigator during the greater part of the year now ending.

MODIFYING EFFECTS OF NEAR INFRARED RADIATION

We have now completed the study, outlined in Year Book No. 45, of the effect

of supplementary treatment with near infrared radiation on the frequency with which X-ray-induced recessive lethal mutations are produced in *Drosophila melanogaster*. Earlier work, summarized in Year Book No. 44, had shown that when near infrared radiation (wave length about 10,000 Å) is used prior to X-rays in the treatment of the spermatozoa, a marked increase occurs in the frequency of detectable chromosomal rearrangements over that in controls receiving only the X-ray dose. On the other hand, pretreatment with near infrared does not increase significantly the frequency of the dominant lethal type of change. The additional data now available indicate that such supplementary treatment has no significant effect in this species on the frequency of production by X-rays of sex-linked recessive lethals.

Utilizing the *CIB* technique, we have examined about 10,000 F₂ cultures (as indicated in table 1) obtained in experiments in which near infrared rays and X-rays were tested independently and in combination with each other. It is evident from these data that near infrared radiation in itself is not effective in inducing the types of change that are represented among the group of recessive lethals. Nor does this type of radiation, when used prior to or subsequent to a 3000-roentgen dose of X-rays, modify to an appreciable extent the frequency of induced lethal mutations, which is about 7 per cent in all these cases.

An additional step in the analysis involved determinations of the frequency of chromosomal rearrangement among the group of recessive lethals. For this purpose, 100 of the 526 lethal mutations detected in our experiments were selected

at random in equal numbers from the combination-treatment series and the controls, and analyzed by the salivary-gland-chromosome method. Among the 50 derived from the combination treatment, 18, or 36 per cent, showed gross rearrangements involving the X chromosome; 11 were found among the 25 lethals examined in the pretreatment series, and 7 among 25 in the posttreatment series. In the control group, 14 out of 50, or 28 per cent, revealed X-chromosome rearrangements. The precise location of the lethal has not been determined with respect to the points of

from a consideration of dose-frequency relations, that radiation-induced recessive lethals and rearrangements result independently from a single type of primary effect. Lea and Catcheside had previously developed a detailed theory of the production of recessive lethals based on this assumption, but Fano has shown in a recent note in *Science* (vol. 106, p. 87, 1947) that their theory meets with serious objections.

Dr. Fano, who is now on the staff of the National Bureau of Standards, was permitted by that agency to spend the summer of 1947 at Cold Spring Harbor, and thus

TABLE 1

LETHAL MUTATION RATE (CIB TESTS) AMONG SPERMATOOZOA OF MALES EXPOSED TO X-RAYS OR TO X-RAYS + NEAR INFRARED RAYS

TYPE OF TREATMENT (X-RAYS IN ROENTGENS, NEAR INFRARED IN HOURS)	NUMBER		PER CENT MUTATIONS
	Sperms tested	Lethal mutations	
NIR (48 hrs)	2316	4	0.17 \pm 0.08
X-ray (3000 r)	3393	253	7.46 \pm 0.45
3000 r + 48 hrs.	1989	145	7.29 \pm 0.58
48 hrs. + 3000 r	1770	171	7.01 \pm 0.61

breakage involved in each rearrangement, but in the light of other studies it is assumed that a lethal and a breakage point will coincide in a large proportion of cases.

Rearrangements of the types represented in this analysis had been found in our earlier experiments to increase about 50 per cent when treatment of the spermatozoa with near infrared radiation preceded a 4000-roentgen dose of X-rays. Since we have not found a corresponding rise in the frequency of the recessive lethals, it appears that the lethals associated with gross chromosomal alterations do not depend for their expression on the production of rearrangements. This might seem to confirm the inference, derived

had occasion to apply the methods developed in his recent comment on the Lea-Catcheside theory to a further discussion of the effect of combination treatments with X-rays and near infrared rays. He has estimated the effect of supplementary treatment with near infrared radiation (1) on the frequency of sex-linked recessive lethals, (2) on the fraction of these lethals which is associated with a rearrangement, and (3) on the frequency of dominant lethals. This was done in each case on the assumptions: (a) that the lethals associated with a rearrangement are due to a position effect, and (b) that recessive lethals and rearrangements result independently from a single type of primary

effect. The symbols developed by Dr. Fano for his note in *Science* have been utilized in the calculations presented below; A , B , C , and D represent classes of lethals associated respectively with no rearrangement, a minute rearrangement, a viable gross rearrangement (VGR), and an inviable (lethal) gross rearrangement (LGR).

The frequency of viable gross rearrangements among sperms available for testing will be indicated by $x = VGR/(1 - LGR)$. We have previously shown that this frequency is raised from about 30 per cent to about 45 per cent (i.e., by about 50 per cent of its value) when infrared pretreatment is combined with 4000 roentgens of X-rays. It will be assumed tentatively that the same increase of 50 per cent takes place when the X-ray dose is 2000 or 3000 r. It will also be assumed that the mean number of breaks per rearrangement is independent of the X-ray dose (within those limits) and of the near infrared treatment.

The frequency of sex-linked recessive lethals among sperms available for testing—i.e., $A + B + C/(1 - LGR)$, in Fano's notation—will be indicated by y . The frequency of those among these lethals which are associated with rearrangements—i.e., $C/(1 - LGR)$ —is proportional to x and will be indicated as kx .

(1a) In this case the frequency of lethals of types A and B —namely, $y - kx$ —should not be affected by infrared treatment, and will be called K . Hence, without infrared treatment, $y = y_0 = K + kx_0$; with infrared, $y = y_1 = K + kx_1$. With 3000 r and no infrared, $kx_0/y_0 = 1/(1 + K/kx_0) \sim 1/3$; hence $K/kx_0 \sim 2$ and $y_1/y_0 = (K/kx_0 + x_1/x_0)/(K/kx_0 + 1) = 3.5/3 = 7/6$, since $x_1/x_0 = 1.5$. As stated previously, an increase of this magnitude, expected on the position-effect hypothesis, was not obtained experimentally.

(1b) In this case, it is $K' = A + B + C + D$ which should not be affected by infrared treatment. We can write $K' = A + B + C/(1 - LGR) - C/(1 - LGR) + C \frac{1 - LGR}{1 - LGR} + D \frac{1 - LGR}{C} \frac{C}{1 - LGR} = y - kx [1 - (1 + D/C)(1 - LGR)]$. Using Fano's notation, $D/C = pq$; also $1/(1 - LGR) = 1 + LGR/(1 - LGR) = 1 + (LGR/VGR) VGR/(1 - LGR) = 1 + px$. Then: $K' = y - kx [1 - (1 + pq)/(1 + px)]$, $y_1 - y_0 = kx_1 [1 - (1 + pq)/(1 + px_1)] - kx_0 [1 - (1 + pq)/(1 + px_0)]$, $y_1/y_0 - 1 = (kx_0/y_0) \{ (x_1/x_0) [1 - (1 + pq)/(1 + px_1)] - [1 - (1 + pq)/(1 + px_0)] \}$. This difference is negative, since $p \geq 1$, $q \geq 1$, indicating that the prevalent effect of infrared is to turn A 's and B 's into unobservable D 's. Its value is closest to zero in the somewhat unrealistic case $p = q = 1$; in this case, using $kx_0/y_0 = 1/3$, $x_1/x_0 = 1.5$, $x_0 = 0.2$ (for 3000 r), we find $y_1/y_0 = 1 - 0.046$. Thus a depression of about 5 per cent or more would be anticipated following pretreatment with near infrared radiation on the assumption that recessive lethals and chromosomal rearrangements result independently from a single type of primary effect, as indicated in table 1. A depression of approximately this order of magnitude has in fact been obtained, although it cannot be claimed to be significant.

(2a) The quantity to be estimated is $kx_1/y_1 = (x_1/x_0)(y_0/y_1)(kx_0/y_0)$. Using the data from (1a), this amounts to $3/7 = 42.6$ per cent at 3000 r.

(2b) Using the data from (1b), the same quantity amounts to 0.525 when $p = q = 1$, otherwise to a still larger fraction. The data obtained experimentally are difficult to appraise with respect to (2a) and (2b), since the numbers are small and the standard errors correspondingly large. Four-

teen rearrangements were detected among the 50 lethals examined in the control series (28 per cent), and 11 among 25 (44 per cent) obtained with pretreatment, which is the type of treatment that effected a 50 per cent rise in chromosomal rearrangements. The increase (from 28 to 44 per cent) can be reconciled with the value expected on the assumptions considered in (2*b*), but no great significance can be attached in view of the smallness of the sample.

(3*a* and *b*) According to current ideas on dominant lethals (see, for example Demerec and Fano, *Genetics*, vol. 29, p. 348, 1944), the fraction of the number of eggs fertilized by treated sperms which develops into adults is given by the product of three factors: (1) the fraction which is fertilized by sperm having no unjoined broken chromosome ends; (2) the fraction fertilized by sperm transmitting no lethal gross rearrangements; and (3) the fraction that escapes other, accidental causes of death. The second of these fractions can presumably be reduced by infrared treatment combined with X-rays, and may be written as $F^{(2)} = 1 - LGR = 1/(1 + px)$. The effect of increasing x is smallest, as usual, when $p = 1$. Taking, therefore, $p = 1$, and (for 2000 r) $x_0 = 0.11$, $x_1/x_0 = 1.5$, we find $F_1^{(2)}/F_0^{(2)} = (1 + px_1)/(1 + px_0) = 0.95$. In our previous study, reported in Year Book No. 44, 51.4 per cent of the eggs hatched after a dose of 2000 r of X-rays, and 46.7 per cent when treatment with near infrared preceded the X-rays. The ratio of these two percentages is 0.91.

These calculations based on a consideration of the effects of X-rays and near infrared rays, together with all the remaining evidence, still indicate that no general theory of lethals and chromosomal rearrangements in *Drosophila* is warranted on the basis of the information now available.

The data provided by these near infrared studies now permit a more comprehensive view than was previously possible of the action of near infrared radiation in modifying the frequency of X-ray-induced chromosomal rearrangements. Since near infrared radiation in itself is not effective in inducing either lethal mutations or chromosomal rearrangements, and since, when used in conjunction with X-rays, it does not alter the frequency of dominant or recessive lethals, we are inclined to the view that this agent operates by so modifying the materials of the chromosome that the chances of recombination are increased among the potential breaks induced by the ionizing radiation. The precise definition of the mode of action of near infrared radiation emphasizes the potentialities of this agent as a tool for separating experimentally the breakage and recombination phases of the process of induced structural change.

The studies combining X-rays and near infrared rays have been extended in an effort to obtain a precise quantitative measure of the effect of posttreatment on the production of induced chromosomal rearrangements. It had previously been found that treatment of males with near infrared rays for any considerable period of time after exposure to X-rays accelerated the mitotic processes so that cells that were not mature at the time of X-ray treatment became available for transfer in copulation sooner than if the males had been stored at temperatures within the range from 18° to 28° C. The technical difficulties involved in this type of experimental procedure have been obviated by exposing females, inseminated by males previously treated with X-rays, to the near infrared rays under conditions so unfavorable for oviposition that very few eggs are deposited during the period of treatment. Larvae developing from eggs laid subsequently,

following removal of the females to yeasted food, have been utilized for salivary-gland-chromosome preparations that are now being analyzed to determine the frequency of chromosomal rearrangement.

The effectiveness of near infrared radiation when used in combination with X-rays in increasing the frequency of chromosomal rearrangement raises the question whether such modification might be obtained if near infrared were combined with other agents that induce chromosome breakage. Chief among these are mustard gas and the nitrogen mustards. We have accordingly undertaken a series of experiments to determine whether the process of structural change induced by nitrogen mustard, methyl-*bis*-(betachloroethyl)amine, is modifiable by pretreatment or posttreatment with near infrared. The tests were begun recently, so that no statistically significant data are available at this writing, but the study is being continued with the assistance of Mr. Harvey Rothberg, Jr., of Princeton University, who has joined the group that is carrying this enterprise to completion.

OBSERVATIONS ON INDUCED CHROMOSOME BREAKS IN THE LIVING CELL

We have long considered that many of the problems concerning the time and mode of action of ionizing radiations in the production of chromosomal breaks might be resolved by direct observation of the living cell. The possibilities of such an experimental approach were explored during the winter of 1946-1947, in co-operation with Dr. J. Gordon Carlson, at the Industrial Hygiene Research Laboratory of the National Institute of Health in Bethesda, Maryland. Cultures of 14- to 16-day embryos of various species of grasshoppers were prepared in a manner that permitted direct observation, under oil-

immersion objectives, of the giant neuroblast cells that cover the ventral surface of the embryo. We had anticipated that the phase-difference microscope might be of considerable aid in obtaining good resolution of the unstained chromatin threads, but in actual practice this optical system provided little advantage over the ordinary microscope, since the mass of cells underlying the neuroblasts in our preparations caused extensive and confusing diffraction patterns. As Dr. Carlson had demonstrated in his earlier studies, however, the trained cytologist soon learns to identify the various phases of mitosis in these hanging-drop preparations, and we were thus able to follow through mitosis cells which had been irradiated at a carefully identified stage in the cycle. In this way we were able to ascertain, for example, that breaks may be induced in the chromosomes of a cell irradiated at late prophase, and that chromosome fragments can then be observed at the succeeding anaphase. Extensive quantitative data remain to be collected before any appraisal can be made of the relative sensitivities of different stages of mitosis. It will be necessary, moreover, to develop methods more adequate than those now available for maintaining the cultures in a state of active division for several hours following their recovery from the mitotic inhibition that is effected by even a small dose of X-rays. Experiments along these lines are being continued at Cold Spring Harbor.

NONHOMOLOGOUS ASSOCIATION OF BANDS OF SALIVARY-GLAND CHROMOSOMES

The project reported in Year Book No. 43 of mapping the positions of heterochromatic and duplicated euchromatic regions along the chromosomes of *Drosophila melanogaster* has been furthered by a series of observations made during the summer

of 1947 by Marcia Kelman Iddles. Up to the present time about 350 cases of pairing between nonhomologous bands in the salivary-gland chromosomes of the Oregon-R stock have been analyzed. In these cases a strand of chromosomal material is stretched between two bands or between one band and a series of others that occupy different loci. Association of this type is more frequent between bands in the same chromosome limb than between bands in different limbs. Sometimes adjacent bands are involved; the two bands may adhere at one end, but separate widely at the other to present a V-shaped or linear pattern, the chromosome appearing broken open at these regions. Pairing of this type has been observed to occur occasionally between the parts of a recognized doublet (for example, between 33A1 and 33A2, or between 70C1 and 70C2); more frequently it occurs in subdivisions, such as 3C, 11A, and 12DE of the X chromosome, which are known from previous studies to include heterochromatic materials. Thus, by accepting nonspecific pairing of the type described as an additional criterion for the localization of heterochromatin, it has been possible to map heterochromatic regions in the autosomes as well as in the X chromosome.

Apart from the association of bands in the presumptive heterochromatic regions, there is a great deal of what appears to be random pairing between a given band and a series of others that occupy various positions in the different chromosomes. Occasionally, corresponding bands in the two closely appressed homologues that constitute the chromosome limb may each be associated with a different band in another chromosome. An appraisal of these diverse observations must await a more complete analysis of the accumulated data. It has been possible, however, to obtain a crude quantitative determination of the amount

of nonhomologous association in the different chromosome limbs. As was to be anticipated from previous observations, bands in the left limb of the second chromosome show the highest frequency, whereas those in the right limb of this same chromosome are least often involved. In earlier studies there had also been intimations of a high degree of association between the tips of the various chromosome limbs, but the data now available suggest that this end-to-end pairing is not much more frequent than the association between the tips and various intercalary regions.

CHEMICAL AND HISTOCHEMICAL STUDIES

Another approach to the problem of the organization of the chromosome at the submicroscopic level involves chemical identification of its constituent materials. Our experiments along these lines have combined the use of enzymes with various histochemical tests. Since such methods of analysis require enzymes of known purity and specificity of action, as well as reliable histochemical procedures, we have devoted considerable energy to attaining these conditions. Isolation by chemical techniques of various cellular constituents will enable us to obtain substrate materials for test-tube confirmation of the nature of the action of the enzymes being studied. In the preliminary phases of the development of these methods we have gained some insight into the organization of the chromosome with respect to the distribution of both proteins and nucleic acids during the various phases of mitosis.

The preparation and assay of crystalline enzymes. Experiments on the preparation and assay of trypsin, chymotrypsin, pepsin, ribonuclease, and deoxyribonuclease for use in our histochemical studies of chromosome structure have been continued. The

results obtained emphasize once again the dangers resulting from the assumption that crystallinity is of itself evidence of purity. Conclusions as to enzyme specificity are certainly unwarranted unless the enzyme being investigated conforms to all the known criteria of chemical and biological individuality, as indicated in Year Book No. 45.

1. The specificity of crystalline ribonuclease: A method for the preparation of crystalline ribonuclease, an enzyme capable

the question whether the loss of properties, considered by the latter group to be due specifically to the depolymerization of ribonucleic acid, may not be attributed either to the loss of protein or to the nonspecific loss of ribonucleic acid due to degradation of the protein to which it was originally bound. It was essential, therefore, to determine the specificity of action of crystalline ribonuclease before using it in our studies of the chemical composition of the chromosomes.

TABLE 2

ASSAY OF VARIOUS SAMPLES OF CRYSTALLINE RIBONUCLEASE

(All values are expressed in activity units per mg. protein nitrogen. The differences between columns 5 and 4 are a measure of the amounts of proteolytic precursors; those between columns 4 and 3, of the amounts of trypsin inhibitor.)

SAMPLE	RIBONUCLEASE UNITS	TRYPSIN UNITS $\times 10^{-4}$, ASSAYED AFTER		
		1 hr. at pH 7.6	1 hr. at pH 1.0	Complete activation
Ribonuclease 1.....	1,490	14	38	38
2.....	1,430	6	26	26
3.....	1,390	134	340	13,500
4.....	1,375	520	1,824	2,640
5.....	1,368	290	1,190	3,650
6.....	1,224	154	702	21,000
Trypsin.....	....	170,000	170,000	170,000
Chymotrypsin.....	....	45,000	45,000	45,000

of depolymerizing ribonucleic but not desoxyribonucleic acid, was described by Kunitz in 1940. Since that time various workers have shown that at least some samples of ribonuclease had, in addition to the ability to degrade ribonucleic acid, the property of hydrolyzing proteins. It was not demonstrated whether this was due to an intrinsic property of the ribonuclease molecule or to the presence of contaminants. Numerous workers have used such preparations to demonstrate the presence of ribonucleic acid in cytoplasm, nucleoli, etc. The above findings, however, raised

Samples of crystalline ribonuclease prepared in our laboratory by the method of Kunitz, and samples prepared by Dr. Kunitz in the laboratories of the Rockefeller Institute for Medical Research, were tested for their ability to hydrolyze denatured hemoglobin. Several representative assays are given in table 2. Every specimen checked showed some proteolytic activity, and many of the samples also manifested additional proteolytic activity after activation, thereby indicating the presence of precursors. Some were also found to inhibit the action of trypsin, and

to a lesser extent than that of chymotrypsin, at pH 7.6 but not at pH 1.0. Experiments have now shown, however, that all these properties were due to impurities present in the preparations and not to ribonuclease itself, since (a) the ratio of these activities to ribonuclease activity varied with the different preparations, and (b) it was possible by varying the experimental conditions to destroy differentially the various activities.

The samples of ribonuclease tested were also found to clot milk and to hydrolyze a substrate specific for trypsin, α benzoyl-L-arginineamide. We are indebted to Dr. Joseph S. Fruton, of the Yale University School of Medicine, for the latter preparation. The proteolytic activity of the ribonuclease could therefore be due to contamination by both chymotrypsin and trypsin. Other peptidases may also be present, but these have not been tested for experimentally. Assuming that one-half of the proteolytic activity was due to trypsin and one-half to chymotrypsin, the median value found for the proteolytic impurities was 0.07 per cent, the range being from 0.035 to 2.6 per cent. Even these small amounts of contaminants, however, may lead to erroneous conclusions when ribonuclease is used as a specific tool; at least one such instance has been described in published material.

The increase in proteolytic activity noted in some samples of ribonuclease after activation was not due primarily to chymotrypsin, since there was little increase in milk-clotting ability. Calculated on the basis of trypsinogen, the precursor(s) constituted from 0 to 12 per cent of the total nitrogen.

2. The preparation of proteolytic-free crystalline ribonuclease: Much effort has been devoted to contriving a method for the preparation of ribonuclease free from proteolytic and potential proteolytic ac-

tivity; for, although it was relatively simple to destroy all the proteolytic enzymes while simultaneously destroying some of the ribonuclease, it was much more difficult to destroy all the former without losing any appreciable amounts of the latter. The method finally devised consists essentially in boiling solutions of crude (or previously crystallized) ribonuclease in 0.2 saturated ammonium sulfate at pH 3 for 5 minutes and then fractionating such preparations with ammonium sulfate between 0.5 and 0.8 saturation. As can be seen from table 3, which gives the results of a typical preparation, this procedure destroys all proteolytic and potential proteolytic activity but leaves the ribonuclease practically intact. The latter can then be crystallized by a slight modification of Kunitz' procedure. Ten different preparations have now been made by this method. In no case has any measurable amount of proteolytic activity been found; that is, there was less than 0.005 per cent of proteolytic enzyme as measured by the digestion of denatured hemoglobin. These preparations did not degrade, proteolytically or otherwise, egg albumin, protamine, histone, thymus nucleohistone, or desoxyribose nucleic acid. The absence of proteolytic enzymes in these preparations has been confirmed by Dr. Walter C. Schneider at the University of Wisconsin, who found, in contrast with results with some preparations previously tested, that they had essentially no effect on the succinoxidase system.

Localization of cellular materials. Chemical analyses carried out in other laboratories during past years have shown that the chromosomes of higher plants and animals consist at least of desoxyribonucleic acid, histones, and tryptophane-containing proteins. Little is known, however, concerning the quantitative changes in the concentration, location, and organization

of these materials during mitosis. There have been some intimations, derived by using ribonuclease, that the ribose type of nucleic acid might also be present in the chromosomes. Since the possibility existed, however, that the action of the ribonuclease preparations used in these tests was attributable not to their nuclease but to their proteolytic properties, these observations were quite inconclusive. The development of a method for the preparation of proteolytic-free ribonuclease, re-

cerning its *in situ* specificity. We hope that our enzymatic studies will eventually settle this controversy, but we still lack, despite our efforts to prepare them, the purified crystalline preparations of desoxyribonuclease necessary for critically evaluating the merits of the arguments pro and con. For coloration of ribonucleic acid, a series of basic dyes such as toluidine blue and safranin has been found satisfactory; the pyronin and methyl green combination developed by Pappenheim and Unna has also

TABLE 3
DESTRUCTION OF PROTEOLYTIC CONTAMINANTS

	CRUDE RIBONUCLEASE		
	Before boiling	After boiling	After boiling and ammonium sulfate fractionation
Ribonuclease units per mg. N.....	646	789	894
Total ribonuclease units.....	1,000,000	960,000	828,000
Trypsin units $\times 10^{-6}$ per mg. N*.....	916	9	<0.1
Total trypsin units $\times 10^{-6}$ *.....	1,420,000	10,944	<100
Potential trypsin units $\times 10^{-6}$ per mg. N†.....	7,100	<4	<4
Total potential trypsin units $\times 10^{-6}$ †.....	11,000,000	<5,000	<4,000

*Assayed after 1 hr. at pH 1.0.

†Assayed after complete activation.

ported in the preceding section, has now given us a tool that will permit a decisive test for the presence or absence of this component.

We have used in this study—both separately and in conjunction with enzymatic degradation of the cellular components—histochemical tests capable of revealing the presence and location, or the absence, of the different types of nucleic acids and proteins. Most workers have relied upon the Feulgen reaction for the localization of desoxyribonucleic acid, and we have temporarily adopted this test, recognizing that certain objections may be raised con-

proved extremely useful. There is no satisfactory method for selectively coloring the histone type of protein, since, with the exception of tryptophane, all the amino acids and types of linkage that are present in proteins and that form the basis of all the protein color reactions are also present in histones. They can be removed from the cell, however, with 0.2 *N* hydrochloric acid. For localization of the tryptophane-containing proteins we have continued to apply modifications of the Bates test reported in Year Book No. 45. Because of the drastic action of concentrated hydrochloric acid on protoplasmic substances, it has been

necessary, in order to lessen the time of the reaction, to make an extensive survey of the effects on the reaction of (1) the concentrations of the different components of the reagent (hydrochloric acid, *p*-dimethylaminobenzaldehyde, and sodium nitrate), (2) oxidizing agents other than sodium nitrate, (3) the age of the solutions, and (4) the various components that constitute the ordinary cytological fixatives. We have now been able, by using smears and sections fixed in alcohol-acetic acid and subsequently hardened, and by greatly increasing the concentration of sodium nitrate, to reduce the reaction time for the development of the blue color specific for the indole nucleus (tryptophane) from one hour to between 30 and 60 seconds. In root tips of *Allium cepa* and of *Lilium tigrinum*, we have found that the blue color is pronounced in the cytoplasm and in the spindle. It is also conspicuous in nucleoli during the prophase and resting stages. The chromonemata in our preparations have shown only a very pale blue color, and we are now attempting to improve the reaction further, so as to determine more precisely the changes that occur in the concentration of the tryptophane-containing proteins during the cycle of mitosis.

A comparison of color reactions before and after treatment with a given enzyme should permit determination of the efficacy of the enzyme in eliminating from the cell the substrate being tested. In actual practice, however, clear-cut results often depend on the degree of control over a series of accessory factors. As an example, the action of the enzyme ribonuclease in removing ribonucleic acid from cells of root tips has been found to be retarded or even inhibited by certain fixatives. In a typical experiment, sections of root tips fixed in five different fixatives—acetic alcohol, and Helly's, Navashin's, Benda's, and Bouin's fluids—were attached to one slide,

and this preparation was immersed in a ribonuclease solution of ca. 400 ribonuclease units per milliliter (2.5 mg. enzyme per ml.) at 60° C. In one-half hour, the pyronin staining component had been completely removed from the acetic-alcohol-fixed root and partially removed from the Navashin- and Helly-fixed roots. The Benda material was untouched by enzymatic action after two hours, and the Bouin-fixed root showed such poor coloration even in the control that no decision could be made about the amount of digestion that had occurred. The type and concentration of buffer in which the enzyme is dissolved greatly modifies the concentration of enzyme required; under certain conditions the buffer itself may effect the removal of cellular materials, or it may interfere with the specificity of the staining reaction. Veronal buffer alone was found to be highly effective in removing the pyronin staining component from control sections. On the other hand, an enzymatic solution containing ca. 700 ribonuclease units per milliliter dissolved in 0.1 *M* phosphate buffer, pH 7.6, gave no reduction in intensity of pyronin staining in 4 hours at 45° C., whereas the same concentration of ribonuclease dissolved in water at the same pH completely removed this component. Even the type of adhesive used in affixing the paraffin ribbons to the glass slide preparatory to digestion and staining was found to alter the reaction. Pitfalls such as these have been recognized by students of histochemistry; they emphasize the necessity for formulating the precise experimental conditions under which a given test is carried out with each type of material.

Having taken these variables into consideration, and recognizing that our experiments are still in their preliminary stages, we have nevertheless been able to demonstrate by histochemical methods that

mitotic chromosomes contain appreciable quantities of ribose as well as deoxyribose nucleic acid. The latter appears to be restricted to the chromosomes, whereas the ribose type is present in the chromosomes, nucleolus, and cytoplasm. Its distribution seems to parallel that of the tryptophane-containing proteins, and it is indeed tempting to suggest that the two may exist in close combination as nucleoprotein. Spe-

cific patterns of distribution, however, must await a detailed analysis of the action on cells at various stages in the mitotic cycle of the nucleases and proteases when used independently and in combination with each other. The completion of such a study, in which we are now engaged, should lead us closer to an understanding of the chromosome as a physiological as well as a morphological entity.

CYTOGENETIC STUDIES OF MAIZE AND NEUROSPORA

BARBARA McCLINTOCK

THE MUTABLE Ds LOCUS IN MAIZE

General considerations. In last year's report a summary account was given of several newly arising unstable gene loci. The instability of all but one of these loci was phenotypically expressed by the appearance in an otherwise recessive plant of sharply defined sectors of dominant tissue or of tissue showing an intermediate condition between recessive and dominant. Each of these sectors arose following a mutation in the unstable locus occurring in an individual cell during the development of the tissue. When an unstable locus is present, the tissues of the plant show a pattern of variegation which is related to the time and frequency of mutations occurring in particular cells during the development of the tissue. Observations of the behavior of the unstable loci have suggested that a common underlying phenomenon is associated with the expression of instability in all the cases examined. Several generalizations may be formulated concerning this phenomenon. Two separable factors are known to be associated with the expression of instability. The first factor is concerned with the particular state of the unstable locus in the cells of a developing tissue. The state of a locus is

reflected by the time of occurrence of phenotypically visible mutations and by the frequency and distribution of these mutations. The second factor is concerned with the mutation at the unstable locus that gives rise to the phenotypically recognizable altered expression of the locus. During the development of a tissue, the state of a locus may remain unchanged. This results in a tissue showing one particular and readily recognizable type of variegation pattern. Changes in the state of a locus may, however, occur. These changes arise abruptly and appear to be associated with an event that occurs during a mitotic cycle. Following such a change, the variegation pattern is altered in the descendants of this cell. There may be fewer or, conversely, more mutations in the descendant cells than would have occurred had the event that gives rise to a change in state not taken place. The evidence suggests that the change in state may be related to the reproductive cycle of the chromosome, for it has frequently been observed that when a change occurs the state of the mutable locus in each sister chromatid may become altered. The state of the mutable locus may be quite different in the two chromatids, and the state in each chromatid, in turn, different from

that which existed in the immediate mother cell. In brief, it is the state of the locus at a particular stage in development that determines the time and rate of future mutations, and this state may be altered by an event occurring at a mitosis often considerably in advance of the genotypic mutation itself.

During the past year attention has been concentrated on one of the mutable loci, because its action and its location are particularly favorable for an analysis of the factors associated with mutability. Furthermore, the type of action at this locus is unique in its cytogenetic aspects and of considerable general interest in this respect alone. In this one case, mutability is expressed not by a visible phenotypic change in the action of a gene, but rather by dissociation of the bonds that normally would maintain a linear cohesiveness of this locus with an adjacent locus in the chromosome. As an ultimate consequence of the mutation, the chromosome is dissociated into two completely detached segments. Because one of these segments is acentric, it is not capable of directed movement in the spindle figure and subsequently is lost to the nuclei of descendent cells. This mutable locus has been designated *Ds* because the most readily recognizable consequence of its action is this dissociation. By both cytological and genetic methods, the *Ds* locus has been placed in chromosome 9, at approximately the position that demarcates the proximal third of the short arm. The acentric segment that is produced as a consequence of a dissociation mutation is composed, then, of the distal two-thirds of the short arm. This segment contains the loci of most of the known mutants of chromosome 9. Collectively, these mutants affect characters of the pollen, the endosperm of the kernel, the seedling, and the mature plant. Consequently, dissociation mutations at the *Ds* locus may be traced

by genetic analyses in all stages of the life cycle when a plant carries dominant alleles and *Ds* in one chromosome 9 and recessive alleles and a normal *ds* locus in the homologous chromosome 9. Whenever a dissociation mutation occurs in a cell during the development of a tissue of such a plant, an acentric segment carrying the dominant factors is produced. This acentric segment is subsequently lost from the nucleus during a mitotic cycle. The result is a nucleus having only the recessive alleles that are present in the homologous segment of the *ds*-carrying chromosome 9. All the cells arising from this cell will be recessive in genotype and also in phenotype, if the expression of the particular recessive factor is cell-specific and if this phenotypic expression is not subject to changes that may be caused by diffusible gene products from the adjacent dominant cells. The presence of a recessive sector in a mature tissue indicates that a dissociation mutation occurred in the ancestor cell that gave rise to this sector. In plants of the given constitution, therefore the mature tissues can be expected to show variegation for recessive sectors. From the size, frequency, and distribution of these recessive sectors in any one tissue the state of the locus in this particular tissue or sector of tissue can be recognized.

Control of Ds activity by Ac. Accumulating evidence indicates that the *Ds* locus will undergo dissociation mutations only when a particular dominant factor is present. This factor is designated *Ac* because it activates *Ds*. *Ac* is probably located in the long arm of chromosome 9, but its exact position has not been determined. By the end of this growing season, the analysis of the action of *Ac* on the *Ds* locus should be well advanced. At the present time the evidence suggests the following relations between *Ac* and *Ds*. If *Ac* is not present, the *Ds* locus is com-

pletely normal in behavior and indistinguishable from *ds*. If, by appropriate crosses, however, *Ac* is introduced into the primary endosperm nucleus, the *Ds* locus again becomes mutable and dissociations may begin to occur shortly after the introduction of *Ac*. *Ac* will not affect a normal *ds* locus, however; in the presence of *Ac*, *ds* remains stable.

Cytological aspects of the action of the Ds locus. Genetic evidence indicated that the dissociation mutations take place relatively late in the development of the sporophytic tissues. This was confirmed by cytological observations of the sporocytes of *Ds Ac* plants. In the sporogenous cells of the anthers of the majority of plants examined, the dissociation mutations—recognized by the constitution of the chromosome 9 bivalent—most frequently occurred in a late-premeiotic nucleus or sometimes in the meiotic nucleus itself. Genetic and cytological evidence also indicates that dissociation mutations may be delayed throughout the period of meiosis and only begin to take place in the following gametophytic nuclei. In some plants, however, dissociation mutations were observed to have occurred in relatively young premeiotic nuclei. The relation of this variable timing of dissociation mutations to the particular state of the *Ds* locus will be discussed later.

In making preparations of the sporocytes with the usual aceto-carmine staining techniques, considerable difficulty was encountered in obtaining an adequate number of well spread and sharply stained meiotic prophase figures. Consequently, it was necessary to attempt an improvement in the techniques. Methods that had been developed in the fall of 1946 for the study of meiotic prophase chromosomes of the fungus *Neurospora* were tried, and found to be likewise superior for similar stages in maize. These methods introduce the

use of lactic acid, either in the fixing fluid or in the staining solution. Young anthers were fixed for 12 to 24 hours in a fresh mixture of four parts of 95 per cent alcohol to one part of lactic acid. The sporocytes in the meiotic prophase states were forced out of the anther in a drop of aceto-orcein; a cover slip was placed over the drop, and the slide gently heated. An unusually sharp differential stain resulted. The cytoplasm was only slightly stained; the chromosomes, in contrast, were brilliantly stained, and the centromeres were sharply delimited in each chromosome. Considerable stretching of the chromosomes sometimes occurred, however, during the flattening of the sporocytes. When equal parts of lactic acid and acetic acid were used in the fixative in place of lactic acid alone, the chromosomes stained sharply with aceto-orcein but were less subject to stretching during the flattening of the sporocytes. A third method involved the restaining of aceto-carmine preparations with an orcein stain consisting of 1 per cent orcein in a mixture of equal parts of lactic acid, acetic acid, and water. Brilliant contrast in staining resulted. Initial use of this stain on the sporocytes did not give satisfactory results.

Some of the major aspects of chromosome 9 behavior that are associated with the presence of the *Ds* locus were reviewed in Year Book No. 45. It is now suspected that the dissociation mutation process is not a simple breakage of bonds at the *Ds* locus, although this is usually the eventual consequence. In making observations of the chromosomes, it was necessary to be able to identify accurately the *Ds*-carrying chromosome in the sporocytes of a *Ds ds* plant. Crosses were made, therefore, between *Ds*-carrying plants with morphologically normal chromosomes 9 and *ds ds* plants having a chromosome 9 with a small terminal knob at the end of the

short arm and a short duplication of chromatin extending beyond the knob. The heteromorphic end of the short arm of the chromosome 9 bivalent in the meiotic prophase of the resulting plants allowed the *Ds*- and *ds*-carrying chromosomes to be readily identified. In these plants, a number of sporocytes were observed in which the *Ds*-carrying chromosome was deficient for the terminal two-thirds of the short arm as a consequence of a previous dissociation mutation in an ancestor cell. In all cases, without exception, it could be determined that only the *Ds*-carrying chromosome had been affected by this action. Some sporocytes were observed, however, in which the *Ds*-carrying chromosome had not simply lost two-thirds of its short arm, but had been subjected instead to some other modification, whose history is not understood at present. Among the aberrant types, those showing the complete loss of the *Ds*-carrying chromosome in a sector of sporocytes in the anther were the most frequent. In the recognized cases, the losses occurred earlier than the more frequently observed dissociations at the *Ds* locus. In other cases, a small sector of sporocytes was present in which the *Ds*-carrying chromosome was missing; in these cases, however, a small ring-shaped chromosome was present in the cells of these particular sectors. This ring chromosome probably is composed of a segment of the *Ds*-carrying chromosome 9, although positive identification could not be made. A few other types of aberrant configurations also were observed. In all these relatively rare types of aberrant behavior, only the *Ds*-carrying and never the *ds*-carrying chromosome was involved. It is obvious that the presence of the *Ds* and *Ac* loci is in some way responsible for these aberrant types of chromosome 9 behavior. It is hoped that a more complete analysis of these relatively rare types of

sporocytes will yield some insight into the nature of the action that occurs as a consequence of the combined presence of the *Ds* and *Ac* loci. It will be necessary to observe many thousands of sporocytes before a sufficient number showing aberrant types of chromosome 9 behavior can be found. With the improved techniques recently developed, it is hoped that this may be more readily accomplished. Until this needed information has been obtained, it would be premature to attempt to project a sequence of events that result directly in a dissociation or in one of the rarer types of alterations involving the *Ds*-carrying chromosome 9.

The stability of the state of the Ds locus.

As mentioned previously, abrupt changes may occur in the expressed pattern of dissociation mutations in a tissue or sector of tissue. The general pattern, in each case, is the product of the time, the frequency, and the distribution of dissociation mutations that have occurred in individual cells during development. At present it is not known to what extent these changes in the expression of dissociation mutations are controlled by altered conditions at either the *Ds* or the *Ac* locus, or at both, or by other genetic conditions not yet identified. Until further evidence has accumulated, the observed patterns will be considered a reflection of the state of the *Ds* locus even though this restricted definition may later require modification. The patterns of dissociation mutations are visible in tissues of plants that have a *ds*-carrying chromosome 9 with recessive factors in its short arm and a *Ds*-carrying chromosome 9 with their dominant alleles. The recessive factors *wd*, *pyd*, and *yg* (*wd*, white leaf tissue; *pyd*, pale-yellow leaf tissue; *yg*, yellow-green leaf tissue), located at or close to the end of the short arm, have been used to determine the pattern of dissociation mutations in leaf tissues of seedlings

or mature plants. The series of alleles *c* (colorless aleurone), *C* (colored aleurone), and *I* (inhibitor of *C* color)—located approximately at the position demarcating the distal third of the short arm—and the recessive factors *sh* (shrunkened endosperm), *bz* (bronze, modifier of *C* color), and *wx* (waxy starch in endosperm and pollen)—located, in the order given, between *C* and *Ds*—have been used to examine dissociation mutations in the endosperm of the kernel. The alleles *Wx* and *wx* have been used to estimate the number of pollen grains in individual anthers of *Wx Ds/wx ds* or *wx Ds/Wx ds* plants that are deficient for the terminal two-thirds of the short arm of chromosome 9 because of previous dissociation mutations in ancestral nuclei.

When silks of plants that were homozygous for *ac* and for *C*, *sh*, *bz*, *wx*, and *ds* received pollen from plants carrying *Ac* and a chromosome 9 with the dominant alleles *I*, *Sh*, *Bz*, *Wx*, and *Ds*, a number of kernels on the resulting *F*₁ ear were variegated because of the presence of sectors of cells with the phenotypic constitution *C sh bz wx*. With a few exceptions, each sector composed of multiple-recessive cells arose following a dissociation mutation that had occurred in the ancestor cell of the sector. Subsequent elimination, during a mitosis, of the acentric segment of the chromosome 9 carrying *I Sh Bz Wx* resulted in the absence of these dominant factors from the descendent nuclei. In crosses involving any one male parent carrying a particular *Ds* and a particular *Ac* locus, the majority of variegated kernels fell into one main class with respect to the type of variegation pattern they exhibited. Great differences in pattern types exist. For example, the majority of variegated kernels on the *F*₁ ears may show a speckled appearance because of the presence of a number of small patches of cells

that are *C sh bz wx* in constitution. The size of a speckle here depends on the time of occurrence of the dissociation mutation. If it occurs very late, the colored speck may be composed of only one, two, or a few aleurone cells, but if it occurs somewhat earlier, the colored speck is composed of more aleurone cells. Crosses involving a different male parent may give rise to *F*₁ ears in which the majority of variegated kernels show early dissociation mutations. These kernels are characterized by large areas of recessive tissue and, in extreme cases, by only small patches of dominant tissue—residual areas where dissociation mutations have not occurred.

In a number of variegated kernels, there were relatively large, sharply defined sectors in which the pattern of dissociation mutations within the sector contrasted greatly with the pattern exhibited by other parts of the kernel. These sectors indicated that a change of state had occurred in the ancestor cell that gave rise to the sector. Often these changes in state occur at a relatively early period in the development of the endosperm. The most instructive cases were exhibited by those kernels in which a change of state could be traced to the first or second mitotic division in the endosperm. A change in state in the first division may give rise to a kernel one-half of which shows one pattern of dissociation mutations and the other half a contrasting pattern of dissociation mutations. Or a kernel may be divided into three or four sectors, each with its own particular pattern, following changes of state that occurred in the first and second mitotic divisions of the endosperm. Because of the free nuclear division that takes place in the early development of the endosperm, this tissue is not ideal for a study of early cell lineages. Nevertheless, early changes in state can be recognized in many kernels. The prospects of de-

termining the contrasting nature of the altered states of two sister chromatids, following a mitotic cycle that introduces a change in state in both chromatids, are considerably better in this tissue than in the sporophytic tissues.

In the sporophytic tissues, dissociation mutations occur late in the life of any one tissue. This is in contrast with the endosperm tissue, where dissociation mutations may occur at any time during development. Changes in state, however, may occur at any time during the development of the sporophytic tissue. In this respect, the two tissues are comparable. Barring heterofertilization, the *Ds* locus in the first endosperm nucleus and that in the zygote nucleus are carried by sister chromatids. If no change of state had occurred in the division that gave rise to these two chromatids, the conditions that govern the states of both *Ds* loci should be alike. Several lines of evidence have indicated that this is probably true. Kernels showing early dissociation mutations in the endosperm give rise, in general, to plants having relatively early dissociation mutations in the sporophytic tissues. Conversely, kernels with late dissociation mutations in the endosperm tissues give rise to plants showing relatively late dissociation mutations in the sporophytic tissues. Present evidence indicates that the state of a particular *Ds* locus may remain relatively unchanged in mos. of the cells of a plant. Plants arising from kernels that showed early dissociation mutations gave rise in the next generation to variegated kernels the majority of which showed early dissociation mutations. Conversely, plants arising from kernels that showed late dissociation mutations gave rise in the following generation to variegated kernels the majority of which showed late dissociation mutations. Even though a *Ds* locus may remain in one

state throughout a number of consecutive mitoses, changes in state nevertheless are not infrequent. At present, no critical evidence is available concerning possible genetic or environmental factors that may influence the state of a locus or its expression as reflected in dissociation mutations. Although changes in state of a locus and the subsequent changes in the frequency and distribution of dissociation mutations are interrelated, the alteration that is associated with a change in state and the alteration that results in a dissociation mutation are distinct and separable.

CONTINUATION OF STUDIES OF THE CHROMOSOMES OF *NEUROSPORA CRASSA*

Study of the mutable loci in maize was interrupted during the fall and early winter of 1946 in order to continue the investigations of the chromosomes of *Neurospora crassa* begun several years earlier. The earlier work was preliminary and exploratory, and no time was spent in obtaining the necessary illustrations of chromosome morphology and behavior during ascosporeogenesis. In addition, the preliminary study indicated a need for improvements in techniques in order that consistently good preparations could be obtained of the chromosomes and nuclei of the ascus. Efforts were concentrated, therefore, on these two objectives. The investigations were conducted at the California Institute of Technology, with the collaboration of Mr. Jesse R. Singleton. Approximately one hundred photomicrographs were taken, illustrating chromosome and nuclear behavior from the pre-fusion stages in the crosier to the binucleated stage in the ascospore. New or modified techniques were devised, which greatly improved the quality of the preparations. This applied significantly to the meiotic prophase stages,

where the chromosomes are greatly extended. In the previous investigation, the minute morphology of the extended chromosomes could rarely be observed, but with the present techniques this morphology is sharply defined in many figures. Mr. Singleton has succeeded in mapping the chromomere organization of each of the seven chromosomes. Each chromosome has an individually recognizable chromomere organization, including deep-staining regions which, because of their positions in the chromosomes, probably represent the heterochromatic regions known to be adjacent to the centromeres. It can now be stated with certainty that no heteromorphic pair of chromosomes is present in *Neurospora crassa*. These techniques have also made it possible to observe more critically the mutual relations of the two homologues of a bivalent during the mid-meiotic prophase stages, that is, before diplotene. Many bivalents were observed in which the two homologous chromosomes were lying side by side but not in direct contact at any point along their length. These favorably oriented bi-

valents showed no relational coiling of the two homologues about each other, and it was obvious that the distance between them was quite constant—amounting to approximately half a micron—so that in their spatial relation they resembled railroad tracks. Technical methods were devised by Mr. Singleton for softening the ascus wall in order to flatten the asci, and also for achieving a sharp differentiation of the spindle figures and the centriole. From preparations kindly donated by Mr. Singleton, photographs were taken to illustrate the peripheral position of the chromosomes in the spindle figures and the rather bizarre organization and behavior of the centriole in the third division in the ascus.

Though the primary objectives of this interim study of the chromosomes of *Neurospora* were fulfilled, a supplementary factor of possibly greater value was the progressive realization of the possibilities for utilizing this material in attacking a number of cytological and cytogenetic problems, both old and new.

MOUSE LEUKEMIA

E. C. MacDOWELL, M. J. TAYLOR, AND L. LEWIS

MATERNAL INFLUENCE UPON SPONTANEOUS LEUKEMIA

In previous Year Books the following steps have been recorded in the study of influence of the mother upon the incidence of spontaneous leukemia: (1) Less leukemia appeared, in reciprocal first-generation hybrids between the leukemic strain C58 and the nonleukemic strain StoLi, when the mother came from the nonleukemic strain. (2) Less leukemia appeared within either form of this cross when the F₁ young were nursed by StoLi than when they were nursed by C58 females. (3) Less leukemia appeared in the

second backcross to inbred StoLi females when these mothers were old than when they were young.

An experiment to confirm this influence of mother's age was started in 1944 (Year Book No. 43, p. 140). During the present year the last mouse in this experiment died, and a preliminary report can be given, although final figures await microscopic diagnosis of certain cases. Young and old StoLi females were mated at the same time to the same C58 males; each mother nursed her own young. Among the 75 female hybrids at whose birth the mothers were 10 to 18 weeks old, the first death

from leukemia occurred at 309 days; by 800 days, 70 per cent had died with leukemia. Among the 89 female hybrids at whose birth the mothers were 34 to 50 weeks old, the first leukemic death occurred at 570 days; by 800 days, 20 per cent had died with leukemia. Thus, with many fewer variables involved, the original indications of a maternal age factor are fully substantiated. If this factor that increases with age and inhibits the development of leukemia should prove to be transmitted by the milk, it would not only provide an interpretation for most of our observations on maternal influence, but also offer an opportunity to isolate the substance so transmitted.

An experiment to test for an effect of the age of the nurse has been in preparation during the past two years, and in the summer of 1947 the 400 test animals were born (within a period of 24 days) and nursed and weaned. As in the previous experiment, the fathers were all from the leukemic strain and the mothers all from the nonleukemic strain: one group 9 to 15 weeks old at the birth of their young (two-thirds being 11 to 12 weeks old); the other group, 36 to 42 weeks old (one-half being 38 to 39 weeks old). Newborn young from each group, which had received no milk from their own mothers, were nursed by mothers of the other group; as controls, others were nursed by their own mothers or other nurses of the same age group. These mice are housed in a room of their own, with the same number from one class in each box, and with the four classes in rotation along the shelves.

A FILTERABLE AGENT ASSOCIATED WITH LINE I

From the beginning of our studies on resistance to transplanted leukemia in-

duced by normal tissue, it was observed that the mice resisting leukemic cells of line I were regularly sick in about a week after the test dose, and later recovered. Since the controls were dying at this time, this sickness seemed to be merely a phase in the process of resistance. But this condition became more interesting when the same symptoms appeared in the same number of days after an injection of microsomic material prepared by Dr. Claude by differential high-speed centrifugation from line I, and also after injection with heated line-I cells (46° C. for 10 minutes), which do not transmit leukemia but do induce active resistance. For years the cause of this sickness has been an outstanding question.

Although many unsuccessful filtration experiments with the early transfers of line I were carried out by Drs. Richter and Zucker at the College of Physicians and Surgeons, the recent development of genetic theory to include self-reproducing, gene-like units free from chromosomes seemed to justify a return to filtration techniques. This was further justified by the apparent activity of certain of Dr. Claude's centrifugates. After 1500 transfers, line I might give different results. The first objective was to obtain the contents of leukemic cells as unchanged as possible, without an intact cell.

The following report covers work undertaken by Miss Taylor. Numerous procedures were eliminated by finding intact cells in the product upon microscopic examination. Dr. Spiegelman, having had a similar objective, proposed his technique of breaking cells by glass beads and carborundum powder in a slowly revolving flask at a low temperature. Dr. McDonald co-operated in working out techniques, shared her cold room (0° C.), and provided apparatus. The ground material, after passing through a pyrex fritted glass

filter, grade *fine*, was found by Dr. R. Miller to include the same population of microscopic particles as before filtration, but whole cells were unquestionably eliminated. This filtrate injected into leukemia-susceptible mice (C58) failed to transmit leukemia, but a sickness appeared in a week that could not be distinguished from the condition mentioned above. Second and third treatments of the same mice with similar filtrates called forth no symptoms, but after the third treatment such mice were still susceptible to line-I leukemia, even when given in a highly dilute dose. This result with cell-free filtrates agrees with earlier experiments in which mice were inoculated with line-I cells subjected to 46.5–50° C. for 10 minutes; the sickness was called forth, and after recovery the mice were still susceptible to intact line-I cells. Miss Taylor discovered that curves of daily body weights show a characteristic pattern for this sickness that records the course of the illness far more objectively than estimations of the reduced activity, dampness of hair, and stickiness of eyes that are its indications. For the first week there is no weight deviation from the controls; then appears a precipitous drop of a gram or more a day for about three days, followed by a leveling off and a slow rise that may not restore the original weight for two or more weeks, many days after other signs of sickness have disappeared. Subsequent experiments proved that the preliminary grinding was unnecessary for the transmission of the sickness. The simple passage of even a highly dilute (10^{-6}) suspension of leukemic tissue through a pyrex *fine* filter gave a material that induced the sickness in the regular time. Within wide limits the concentration of the dose made no difference. Further independence of this agent from leukemic cells was demonstrated by transferring spleen from a filtrate-treated mouse

at the height of the sickness to a normal host. The sickness appeared at the end of a week, and the same result followed a second subtransfer.

Drs. E. Racker and Mark Adams, of the Department of Bacteriology, New York University College of Medicine, in summer residence at the Biological Laboratory, became interested in this problem, and they have followed the work in detail and have made valuable suggestions. Both men were inclined to interpret Miss Taylor's results as indicating the presence of a virus, but subsequently in the hands of a virus specialist a bacterial infection was reported that caused intensive efforts for half the year to be turned toward a search for significant bacteria. To this work Dr. Kelner, of the Biological Laboratory, gave considerable time and assistance, and the bacteriological services of the Department contributed sterilized glassware and media. But this endeavor was fruitless. Various bacteria were found both in the transplanted leukemias and in uninoculated mice directly from the breeding colony, but there was little consistency in occurrence and their pathogenicity was in question. Bacteria found in one transfer of a transplanted line would be entirely absent from a later transfer without recognizable change in the characteristics of the line. When it gradually became clear that neither was the colony threatened by an epidemic, nor the transplanted lines by extinction, the road became clear to undertake the critical filtration experiment which, with Dr. Adams' active co-operation, has just been carried out. A broth suspension of spleen from a mouse inoculated with line-I leukemia was passed through a pyrex filter (*fine*); part of this was inoculated into normal C58 mice and part was passed through a Seitz filter and then inoculated. Both filtrates induced the characteristic symptoms and the sudden

weight loss beginning on the eighth day. It seems probable that this filterable agent has been present in line I for a long time and has been responsible for the "sickness" that has held our attention. It has regularly appeared in C58 mice about a week after first inoculation with line I, when death from leukemia was prevented by previously induced resistance or was sufficiently delayed by high dilution of the dose of cells. Although this sickness has been observed many times over the years, very little can be said about its internal effects. The white-blood-cell counts are high, and the smears of blood have been called leukemoid by Dr. R. Miller. Two mice killed at the height of the sickness after inoculation with a filtrate showed mild lymphoid hyperplasia and moderately enlarged spleens.

To summarize, a filterable virus-like agent of mild pathogenicity, carried along

with the transplanted leukemia of line I, has been found, which can be passed from mouse to mouse by tissue transplantation without mortality or the appearance of leukemia. This agent has probably existed in line I for more than ten years. A single infection is followed by firm immunity, which has been tested after two months and found still effective. All C58 mice tested have been susceptible. The failure of mice immunized to this agent to resist even highly dilute doses of leukemic cells indicates that the resistance that can be induced to line-I leukemia is a different phenomenon. The action of this virus-like agent upon lymphoid tissues, however, is definitely leukemoid; and questions are raised bearing on its origin, its variations, its modification of the pathology of leukemia, and its possible influence upon resistability and variability of leukemic cells.

GENETIC STRUCTURE OF NATURAL POPULATIONS

TH. DORZHANSKY, *Columbia University, New York*

Cyclic seasonal changes in the genetic structure have been discovered in the populations of the fly *Drosophila pseudoobscura* on Mount San Jacinto, in California (see Year Books Nos. 40, 43, 44). The changes involve the relative frequencies of certain gene arrangements in the third chromosome of the fly. The frequency of the so-called Standard gene arrangement decreases during the spring and increases during the summer, whereas the frequencies of the Chiricahua and Arrowhead gene arrangements wax in spring and wane in summer. The changes seem to represent adaptive responses of the species to the seasonal alterations in the environment in which it lives. This finding has presented an opportunity for an observational and experimental approach to the problem of the action of natural selection.

EXPERIMENTS WITH FLIES DERIVED FROM THE PIÑON FLATS POPULATION

A simple apparatus called the population cage has been constructed, which enables one to maintain populations of *Drosophila pseudoobscura* of known genetic composition, and to study the changes that may occur under controlled laboratory conditions (see Year Books Nos. 43, 45). Some changes analogous to those known to take place in nature have, indeed, been observed in the population cages. The early experiments were made with flies descended from wild progenitors collected at the locality called Piñon Flats, on Mount San Jacinto, California. Artificial populations were made consisting of flies with Standard and Chiricahua, Standard and Arrowhead, and Arrowhead and Chiri-

cahua chromosomes. It was found that at a temperature of 16° C. the relative frequencies of the chromosomal types present in the initial population of a cage remain unchanged generation after generation. In the same way, no changes take place in the population at Piñon Flats during autumn and winter, when low temperatures prevail. But at temperatures close to 25° C., changes do occur in the population cages, as they do in summer in the natural populations. Furthermore, these changes proved to be of a very interesting kind. No chromosomal type entirely supplants its competitor (an exception to this rule, found in a population of flies descended from Mather progenitors, is mentioned below). Instead, the population gradually approaches an equilibrium state, in which the competing chromosomal types are present in definite proportions. In mixtures of Standard (ST) and Chiricahua (CH), and of Standard and Arrowhead (AR), the Standard chromosomes reach at equilibrium a frequency of about 70 per cent. In mixtures of Arrowhead and Chiricahua, the equilibrium value of Arrowhead chromosomes appears to be around 75 per cent.

The failure of the competing chromosomal types to displace one another is best explained on the assumption that individuals homozygous for the respective chromosomes (ST/ST, CH/CH, AR/AR) have lower adaptive values (i.e., survive and reproduce at lower rates) than the chromosome heterozygotes (ST/CH, ST/AR, AR/CH). Since the changes observed in the population cages, as well as in nature, are extremely rapid (see Year Books Nos. 44, 45), the differences in the adaptive values must be very large. Professor Sewall Wright, of the University of Chicago, has computed that, taking the adaptive value of ST/CH heterozygotes to be 1.0, that of ST/ST homozygotes is

about 0.7, and that of CH/CH homozygotes as low as 0.4. The finding of such large differentials among normal constituents of a natural population has been most unexpected, since it has been customarily assumed in modern biology that the intensities of natural selection operative in nature are, except for abnormalities and pathological conditions, very low. Moreover, these differentials characterize the chromosomal types only at relatively high temperatures, and seem to be diminished or removed altogether at 16° C. The origin and the biological meaning of so extraordinary a situation present a fascinating problem.

The first question that arises is whether the adaptive properties of the ST, CH, and AR chromosomes discovered in the Piñon Flats population are intrinsic attributes of the chromosomes having these gene arrangements. Indeed, these chromosomal types occur not only in the Piñon Flats population, but also in populations of the whole Pacific coast, from British Columbia to Lower California. Would the ST, CH, and AR chromosomes behave similarly, then, regardless of the particular locality from which they were derived? Such a similarity would, in general, be expected if the adaptive properties of a chromosome were caused directly by the arrangement of the genes in it (position effect). Chromosomes with the same gene arrangement may behave differently if their properties are determined by the quality of the genes that they carry. Observations and experiments on the populations of several localities have, therefore, been undertaken.

POPULATIONS LIVING AT DIFFERENT ELEVATIONS IN THE SIERRA NEVADA

Thanks to the courtesy of the Division of Plant Biology of the Carnegie Institution, the writer has been able to make ob-

servations on the population of *Drosophila pseudoobscura* of the Sierra Nevada, using as a base the facilities of the Division at Mather, California. The unfailing hospitality of Drs. J. Clausen, D. D. Keck, and W. M. Hiesey, as well as of Drs. H. A. Spoehr and C. S. French, the former and present Chairmen of the Division, is gratefully acknowledged. Mather is located slightly more than 300 miles northwest of San Jacinto, at an elevation of about 4600 feet, on the western slope of the Sierra Nevada.

During the summers of 1946 and 1947, samples of the populations of *Drosophila pseudoobscura* and of the related species *Drosophila persimilis* were taken at Jacksonville (elevation 850 feet), Lost Claim Campground (about 3000 feet), Mather (4600 feet), Aspen Valley Ranger Station (6200 feet), Porcupine Flat (8000 feet), Tuolumne Meadows (8600 feet), and Timberline Station (9900 feet). These localities form an approximate west-east transect of the Sierra Nevada. The distance between the extreme localities, Jacksonville and Timberline, is about 60 miles.

The data are still incomplete, but the main conclusion that follows from them is no longer in doubt. The populations that live in the different localities sampled differ in relative frequencies of Standard and Arrowhead chromosomes, the differences being correlated with the elevations of the respective localities. The Jacksonville population contains about 45 per cent of ST and 25 per cent of AR chromosomes. At Lost Claim, the average frequency of ST falls to about 40 per cent, and that of AR rises to about 35 per cent. At Mather, ST amounts to, roughly, 30 per cent, and AR to 35-40 per cent. At Aspen Valley, ST dwindles to between 20 and 30 per cent, and AR rises to between 40 and 50 per cent. In the higher localities the species *Drosophila pseudoobscura* becomes much less

frequent than *Drosophila persimilis* (the latter being rare at lower elevations), but samples obtained had 15 per cent, or less, of ST chromosomes, and more than 40 per cent of AR chromosomes. In contrast with Mount San Jacinto—where Standard and Chiricahua do, and AR chromosomes do not, show elevational changes—in the Sierra Nevada the frequencies of the CH chromosomes are relatively uniform at different elevations (or, possibly, increase slightly at the higher altitudes).

The details of the seasonal changes in the Sierran populations are not quite clear at present, although there is no doubt that seasonal changes do occur. The data now available suggest that at Aspen Valley, Mather, and Lost Claim seasonal changes are rather pronounced, but that these changes are quite different in kind from those observed on Mount San Jacinto. In the three Sierran localities the relative frequency of the ST chromosomes increases, while the frequency of AR decreases, as the season progresses from spring to autumn. A reversal of the changes evidently takes place during winter. At Piñon Flats and Andreas Canyon, on Mount San Jacinto, no changes have been recorded in autumn and in winter, whereas during the spring and summer ST and CH chromosomes are involved in the cyclic alterations of frequencies. On Mount San Jacinto, as well as along the Sierran transect the fly populations of the higher localities reach maximum densities during late summer, whereas in the lower localities the populations contract in size during the summer, owing presumably to the excessive heat.

The chromosomal composition of the populations in the lower localities on San Jacinto (Andreas, Piñon) approaches in late spring and early summer that of the population of the higher locality (Keen Camp), which at this time is expanding

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The chromosomal composition of the populations in the lower localities on San Jacinto (Andreas, Piñon) approaches in late spring and early summer that of the population of the higher locality (Keen Camp), which at this time is expanding

in numbers. This fact has misled some authors into believing that the changes in the chromosomal constitution observed at Andreas and Piñon were due to an influx of flies from the higher localities. It stands to reason, however, that a migration of flies from Keen to Piñon and Andreas could change the composition of the populations of the latter two localities in the direction of the Keen population, but could not produce the reverse change so as to make the changes cyclic. Moreover, the populations of Piñon and Andreas change during the summer in the direction away from the composition of the Keen population, at the time when the population of the latter locality is expanding and reaching maximum density. Finally, the rate of dispersal of the flies is known to be far too low to produce the postulated migrations (see Year Book No. 45).

Comparison of the altitudinal differences in the incidence of the chromosomal types in the localities of the Sierran transect with the seasonal changes in these localities is very instructive. It will be recalled that the frequencies of ST chromosomes decrease, and those of AR increase, as one ascends from the lower to the higher elevations. However, in at least some of the localities, at mid elevations, the frequencies of ST increase and those of AR decrease as the growing season progresses and the weather becomes warmer. In other words, the populations of relatively higher localities come, during the warm season, to resemble in composition the populations of the lower localities. One reason for excluding the migration hypothesis is that the population densities in the lower localities dwindle when the populations of the higher localities begin to resemble the former in composition. The available facts are consistent with the view that, in the Sierran populations, the carriers of ST chromosomes are better adapted to the en-

vironments prevailing at lower elevations and at warmer seasons, whereas the carriers of AR chromosomes prefer cooler localities and seasons. If this is so, natural selection would tend to increase the frequencies of ST chromosomes in the populations of the lower localities and during the summer, and to have the opposite effect in the higher localities and during cold weather.

It is most instructive to compare the results just outlined with those obtained by Drs. Clausen, Keck, and Hiesey, of the Division of Plant Biology, in their very important work on the local races (ecotypes) of some plant species. These investigators found that plant species that occur in diverse environments are often differentiated into genetically distinct populations—races—which are adapted to survive and to reproduce most efficiently in the particular environments of their occurrence. This is very often the case with representatives of the same species growing at different elevations. A transect of the Sierra Nevada, approximately coinciding with the one used by the present writer, has disclosed many excellent examples of altitudinal races of plants. Clausen, Keck, and Hiesey have explained the origin of the adaptive differentiation observed by them by supposing that natural selection leads to differential increases in the frequencies of different genotypes in different environments. The genotypes best fitted to survive in each environment become established, then, as the predominant, or exclusive, components of the populations in that environment. The fly *Drosophila pseudoobscura* exhibits essentially the same kind of differentiation into altitudinal races that was found by Clausen, Keck, and Hiesey in the plants studied by them. Since the fly, however, is capable—at least at the lower elevations—of producing several generations per year, it under-

goes the process postulated by these investigators regularly and cyclically, twice every year.

BEHAVIOR OF THE MATHER AND KEEN CAMP CHROMOSOMES IN POPULATION CAGES

The observations on the altitudinal and seasonal changes in the frequencies of the chromosomal types in the Sierra Nevada strongly suggest that these chromosomes have different properties from the analogous chromosomes on Mount San Jacinto. Beginning with the winter of 1945-1946, a series of experiments has been conducted with population cages that contained known mixtures of chromosomes derived from the Mather population in the Sierra Nevada, and from the Keen Camp population on Mount San Jacinto. These experiments are now in the main completed, but their results have not yet been subjected to a proper mathematical analysis. The following statement of the results of these experiments is therefore tentative.

A population cage (no. 30) was started in December 1945 with 33 per cent Standard and 67 per cent Chiricahua chromosomes of Mather origin, and was kept at 25° C. By June 1946 it contained about 77 per cent ST and 23 per cent CH. In September 1946 this cage was transferred to a temperature of 15° C. Its population underwent no further change till January 1947. The behavior of the ST and CH chromosomes of Mather origin is, thus, about the same as that of the same chromosomal types from Piñon (see above), except that the equilibrium value for ST seems to be slightly higher for Mather than for Piñon.

Two population cages (nos. 29 and 32) were started in December 1945 with mixtures, respectively, of 70 per cent ST and 30 per cent AR, and 19 per cent ST and 81 per cent AR, chromosomes of Mather

origin. The cages were kept at first at 25° C. The frequencies of the ST and AR chromosomes in these two cages converged, reaching an approximate equality by June-July 1946. Cage no. 32 was transferred in September 1946 to a cold room at 15° C. No changes took place in this cage until January 1947. From then until June 1947, this cage was exposed alternately to room temperature and to a cold-room temperature of about 2° C. The transfers from one temperature to the other were made at first at approximately weekly, and later at daily, intervals. No significant changes occurred till June 1947, although, taken at face value, the frequency of ST rose slightly (to 56-57 per cent). Since the competition of ST and AR chromosomes from Piñon Flats leads to equilibrium at about 70 per cent ST (see above), it may be taken as established that the Sierran chromosomes and those from Piñon Flats have different properties. The competition of the AR and CH chromosomal types of Sierran origin also leads to a result clearly different from that obtained with the same chromosomal types from San Jacinto; the equilibrium value is about 57 per cent AR and 43 per cent CH for Mather chromosomes, compared with more than 70 per cent AR and less than 30 per cent CH for Piñon chromosomes.

The Keen Camp locality is only about 15 miles distant from Piñon Flats and from Andreas Canyon. Despite such close geographical proximity, the Keen Camp population showed remarkably different behavior from the populations of Piñon and Andreas. In contrast with the regular cyclic changes at these two localities, no cyclic seasonal changes in the frequencies of the chromosomal types have been observed with certainty at Keen. Instead, the Keen population showed a sustained trend of change from 1939 to 1946 (the period for which observations are available),

which led to a gradual increase in the frequency of Standard, and to a decrease in the frequencies of Arrowhead and Chiricahua chromosomes (see Year Book No. 45). It seemed a most intriguing problem to investigate whether the difference in behavior between the Keen population, on the one hand, and the Piñon and Andreas populations, on the other, was due to differences in their genetic structures or to differences in their environments. Experimental evidence suggests that the former are at least partly responsible. A population cage (no. 26) was started in November 1945 with a mixture of 32 per cent ST and 68 per cent AR chromosomes of Keen Camp origin. The cage was kept at 25° C. By March 1946, an equilibrium was attained at 60 per cent ST and 40 per cent AR, which persisted till June of the same year, when the cage was transferred to a cold room at 15° C. No further changes occurred until January 1947. The equilibrium point for ST-AR chromosomes of Keen Camp origin seems, then, to lie between those for the same chromosomes of Piñon Flats origin and of Mather origin (see above). An experiment with AR and CH chromosomes of Keen Camp origin gave results resembling those obtained with the same chromosomal types from Mather, but differing sharply from the results with flies from the geographically much nearer Piñon Flats locality.

AN EXCEPTIONAL EXPERIMENT WITH MATHER CHROMOSOMES

In all the experiments referred to up to now, whenever the composition of the population in a population cage underwent changes, these changes led to the establishment of an equilibrium at which all the chromosomal types introduced into the population were preserved with definite frequencies. As stated above, this indicates

that the adaptive values of individuals heterozygous for chromosomes with different gene arrangements are higher than those of chromosome homozygotes. The populations of the Sierra Nevada include, besides the frequently occurring chromosomal types having Standard, Chiricahua, and Arrowhead gene arrangements, some less common chromosomal types, which, because of their relative rarity, could not be used in artificial experiments. Only one of these rare types, called Tree Line (TL), was found in the Mather population in numbers which permitted its inclusion in the experiments (its frequency at Mather ranges from 4 to 10 per cent of the total number of chromosomes).

Population cage no. 31 was started in December 1945 with 45 per cent ST and 55 per cent TL chromosomes of Mather origin. By May 1946, the frequency of TL had fallen to only 18 per cent, and by November of the same year to about 1 per cent. It seems that in this cage the changes were leading to a complete displacement of TL by ST chromosomes. Such an outcome of the competition between the two chromosomal types is possible only if the heterozygotes (TL/ST) are less well adapted, at least under the conditions of the experiment, than the Standard homozygotes (ST/ST).

It may be asked why the Tree Line chromosomes continue to exist at all in the Mather population. If both the heterozygotes, TL/ST, and the homozygotes, TL/TL, are inferior to ST homozygotes, natural selection would be expected to eliminate the TL chromosomes completely. A possible answer to this question is provided by the results obtained in population cage no. 33, which contained Tree Line and Arrowhead chromosomes derived from the Mather population. The outcome of this experiment was quite different from that of no. 31 described above. The

population of no. 33 reached equilibrium at about 75 per cent AR and 25 per cent TL. It must be concluded that the TL/AR heterozygotes are adaptively superior to both TL/TL and AR/AR homozygotes. Now, in the natural populations of Mather and other Sierran localities, the Tree Line, Standard, and Arrowhead chromosomes always occur. TL/ST, as well as TL/AR, heterozygotes are always present in these populations, together with some ST/ST and AR/AR, and a few TL/TL, homozygotes. Although the adaptive value of TL/ST heterozygotes is low as compared with that of ST/ST, that of TL/AR heterozygotes is higher than that of AR/AR, and possibly also than that of ST/ST. Natural selection would tend, then, to retain TL chromosomes in the population, but at a frequency level lower than that of AR and of ST chromosomes. This is precisely what was observed.

ARTIFICIAL POPULATIONS CONTAINING MIXTURES OF CHROMOSOMES OF DIFFERENT GEOGRAPHIC ORIGIN

As the experiments reviewed above had demonstrated that chromosomes with the same gene arrangement derived from geographically different populations may have different properties, the logical next step in the experimental program was to test the behavior of populations composed of chromosome types of different geographic origin. Such populations may easily be created artificially in population cages by crossing flies whose ancestors were collected in different localities. In nature, they are probably rare, since the only way in which they can be formed is through accidental transport (for example, by wind) of individuals from one population to a foreign territory. Nevertheless, the behavior of such artificial populations may be very enlightening in its bearing on

several problems relating to natural populations.

The experiments were started in December 1946, and are at present well under way. After some preliminary trials, the following technique was adopted. Flies homozygous for a certain gene arrangement—say, for Standard of Mather origin—are crossed, in regular *Drosophila* culture bottles, to individuals of the opposite sex homozygous for another gene arrangement of different origin—say, for Chiricahua from Piñon Flats. The offspring of this cross are all heterozygous for Mather and for Piñon Flats chromosomes. These offspring are placed in a population cage in numbers sufficient to produce an overpopulation of larvae in the food introduced into the cage. Since the initial population of the cage consists of heterozygotes only, the first generation of eggs and larvae in the cage will necessarily consist of 25 per cent homozygotes of each of the two types (ST/ST from Mather, and CH/CH from Piñon), and 50 per cent heterozygotes (ST/CH) for chromosomes of the two different geographic origins. If at any developmental stage before the emergence of the adults the two types of homozygotes and the heterozygotes are not equally viable, the theoretical proportions, 25:50:25, will not be realized among the adults. Accordingly, the adults of the first generation emerging in the population cages are tested for their chromosomal constitution. Although such tests are very laborious if many flies are involved, this experimental procedure is expedient. Indeed, comparison of the theoretical proportions with the ratios in which the three chromosomal constitutions actually appear among the adults permits a direct estimate of the coefficients of the differential mortality that may have taken place in the population cage. Such estimates are difficult to obtain by any other procedure.

Five successful experiments of this type, carried out in collaboration with Miss C. Madison, have given quite consistent results, showing that the viability of individuals heterozygous for chromosomes with different gene arrangements of different geographic origin lay between the viabilities of the two corresponding homozygotes. In all these experiments, chromosomes from Mather and from Piñon Flats were involved. In four out of the five experiments, the viability of the homozygotes for chromosomes of Mather origin proved to be higher than that of the homozygotes for Piñon Flats chromosomes.

The differential viabilities observed in the experiments described above may or may not reflect differences in the adaptive values of the individuals of the different chromosomal constitutions. It must be kept in mind that higher survival value of a genotype in, for example, the larval stage may be offset by lower survival or reproductive value of the same genotype in the adult stage. If, however, the observed viability differentials may be taken as indications of the selective values in general, then the outcome of the experiments with population cages containing chromosomes of geographically different origins will be radically different from that of the experiments with mixtures of chromosomes derived from the same population. As shown above, individuals heterozygous for chromosomes with different gene arrangement from the same population are, with the single exception mentioned in the preceding section, adaptively superior to chromosomal homozygotes. Hence, in experiments of this kind, the selective process leads to an equilibrium state in which all competing chromosomal types are preserved. This is what happens in the population cages as well as in natural populations. On the other hand, if the heterozygotes for chromosomes of different

geographic origin are adaptively inferior to at least one of the homozygotes, the selective process will lead to the establishment of one and to elimination of all other competing chromosomal types. Whether or not this will actually be the outcome of the experiments on populations of geographically mixed origin remains to be seen.

ADAPTIVE EVOLUTION IN SOME POPULATIONS OF *DROSOPHILA PSEUDOOBSCURA*

The evidence reviewed above permits some insight into the nature of the evolutionary processes which lead to the adaptation of populations to their environments. It has been known for some time that natural populations of some species of *Drosophila* vary with respect to the gene arrangement in their chromosomes, most of the variation being due to inversions of chromosome sections. It is now clear that the evolutionary significance of the chromosomal inversions is due to their property of reducing or suppressing crossing-over in some chromosome sections in the inversion heterozygotes. Thus adaptively valuable gene combinations, $A'B'C'D'$ and $A''B''C''D''$, may exist in the same population without a constant loss of adaptive fitness, owing to crossing-over and to the production of adaptively inferior types, $A'B''C''D''$, $A'B'C'D''$, etc. The possibility that some gene arrangements may be valuable because of the position effects which they produce is not to be dismissed, but there can be no doubt that the adaptive properties of chromosomes in natural populations are often determined by their gene contents rather than by the gene arrangement.

The adaptive value of a chromosomal type in heterozygotes with other chromosomal types present in the same population may be more important than the adaptive

value of the same type when homozygous. This situation is made possible because, in many natural populations of *Drosophila pseudoobscura*—including the populations that have been employed in our experiments—structural (inversion) heterozygotes are more common than are the homozygotes. The process of natural selection, therefore, encourages the spread of those gene complexes in the chromosomes with one gene arrangement which produce superior heterozygotes with the gene complexes carried by the other chromosomal types present in the same population.

This "coadaptation" of the gene complexes apparently takes place separately and independently in populations which reside 300 miles, or perhaps even as little as 15 miles, from each other. A type (or types) of structural heterozygotes is evolved in each population, which is adapted to the environment prevailing in the particular region where that population lives. The coadaptation of the gene complexes being independent in local populations, the hybrids produced when the populations are intercrossed are adaptively inferior to the members of the parental populations. Thus, intrapopulational heterosis is compatible with a loss of vigor following hybridization of populations. This, evidently, will restrict the effectiveness of migration of flies from one population to another. It may also, under conditions which cannot be discussed in this report, initiate the splitting of an originally single species into two or more derived ones, and the development of reproductive isolating mechanisms between the latter. Further studies in this field may lead to a clarification of the very difficult problem, why some species retain their unity despite a wide geographic distribution and despite the occupation of a variety of environments, while other species split up into

swarms of derived species, each restricted to a small area and each ecologically specialized. However that may be, the situation observed in *Drosophila pseudoobscura* is among the best evidence available for the efficiency of natural selection in evolution. The coadaptation of the gene complexes in local populations could not arise in any other way than through natural selection. It is interesting to find that in some populations the process of coadaptation has not been completed, and one of the chromosomal types, such as Tree Line in the Mather population, produces heterozygotes adaptively superior to the homozygotes only with some (Arrowhead) but not with other (Standard) chromosomal types. Possibly this situation indicates that one of the chromosomal types is a relative newcomer to the territory in which it is now found.

It must not be supposed, however, that the evolutionary pattern found in the populations of *Drosophila pseudoobscura* examined will occur in all organisms, or even in all species of *Drosophila*. Perhaps the most remarkable feature of this pattern is precisely that it permits an extreme plasticity and diversification of the evolutionary adaptations. In some of the San Jacinto, and in the Sierran, populations of *Drosophila pseudoobscura* the biological function of the chromosomal polymorphism is at least partly concerned with the adaptation to different seasonal environments. Yet in the Keen Camp population no seasonal changes occur. There is some evidence that the chromosomal polymorphism in *Drosophila persimilis* and in *Drosophila robusta* is not connected with seasonal adaptation. Finally, some populations of *Drosophila pseudoobscura* that occur in Arizona and in New Mexico are homozygous for a single chromosomal type (Arrowhead). This may mean that,

occasionally, a highly adapted homozygous type is selected, which would make the chromosomal polymorphism unnecessary.

NATURAL SELECTION OF BENEFICIAL MUTATIONS IN LABORATORY CULTURES OF *DROSOPHILA*

It is well known that mutations that arise in laboratory cultures of *Drosophila* are mostly deleterious, or at best neutral, to the viability of their carriers. This fact seems to contradict the view, now held by most biologists, that the mutation process supplies the raw materials of evolution. The apparent contradiction is usually resolved by supposing that some mutations, although harmful in the environment in which the species normally lives and in combination with other genes normally present in the species, may be useful in other environments and in combination with other genes. Indeed, the "normal" species genotype is a product of a long process of natural selection which has brought about an adjustment of this genotype to the "normal" environment; any mutation that is likely to be observed in our experiments has probably taken place many times in nature, and, consequently, has had the chance of being tested by natural selection and of becoming a part of the "normal" genotype. It follows, then, that "useful" mutations can be found mainly in experiments in which a living species is placed in "abnormal" environments, or in which the initial materials have an "abnormal" genetic constitution. This working hypothesis has been tested by means of experiments conducted, in collaboration with Mr. B. Spassky, from 1942 to 1946.

In these experiments, we used seven strains of *Drosophila pseudoobscura* which were homozygous for second or for fourth chromosomes known to reduce the via-

bility of their carriers below the normal (wild-type) level. Mutations were looked for which would bring the viability of these strains back to normal. Some of the strains also showed development rates slower than that characteristic of "normal" flies; and mutations that might accelerate the development to the normal level were expected. The technique of detection of the hoped-for mutations (or modifier recombinations) was as follows. The seven initial strains, each in two parallel sublines, were kept in deliberately overcrowded cultures for fifty consecutive generations. The male progenitors of one of the sublines of each strain received, in every generation, 1000 roentgen units of X-rays, the other subline receiving no treatment. The overpopulation resulted in acute competition for food among the larvae and the adults, and in a stringent natural selection for genetic variants that would improve the viability, or accelerate the development rate. At intervals of several generations, the viability and the development rates of all the sublines were tested, with the aid of a genetic method which cannot be described here in detail; suffice it to say that this method consisted in observing the deviations from the ideal Mendelian proportions that arose when the chromosomes of the lines subjected to selection were tested against chromosomes marked by standard mutant genes.

In eleven out of the fourteen homozygous sublines, statistically significant improvements of the viability were observed. In seven sublines, these improvements were quite striking; in some cases, the viability of a line which acted as a semi-lethal at the beginning of the experiment was brought up to normal or nearly so. The improvements first became noticeable in some of the lines near the beginning, in others toward the middle, and in still others toward the close of the experiments.

Accelerations of the development rate were also observed. No appreciable difference was noted between the X-rayed and the untreated sublines.

In parallel experiments, the seven initial strains were kept for fifty generations in a "balanced" condition. "Balancing" is a genetic technique whereby a chromosome is transmitted from generation to generation through heterozygotes only, the homozygotes not being used as parents. A chromosome kept in a "balanced" condition is sheltered from the effects of natural selection, to the extent that any recessive mutant that arises in it is retained regardless of the viability effects that this mutant

may have when homozygous. Two parallel sublines of each strain were kept, one being treated with X-rays and the other untreated, as described above for the homozygous sublines. Recessive lethals or semilethals appeared in three of the untreated and in five of the X-rayed "balanced" sublines. Three untreated and two X-rayed sublines did not change in viability to any appreciable extent, and one untreated subline showed a slight improvement. The contrast between the homozygous and the "balanced" lines was thus very striking; improvements were observed in most of the former, and degeneration in most of the latter.

CHROMOSOME STUDIES ON GALL MIDGES

M. J. D. WHITE

The gall midges (Cecidomyiidae) are a group of dipterous flies which are unique in that the number of chromosomes in the germ line (primordial germ cells, spermatogonia, and oögonia) is very much greater than the number present in the somatic nuclei. Previous studies had shown that in *Miastor metraloas* there are 48 chromosomes in the germ line of both sexes, 12 in the somatic cells of females, and 6 in the somatic cells of males. In this species the size differences between the individual chromosomes are sufficiently great so that one can be sure that the male som. is haploid and the female som. is diploid. Actually, a number of the somatic tissues are endopolyploid in both sexes, so that much higher numbers of chromosomes occur in some of the somatic cells, but male and female embryos begin their development with haploid and diploid somas, respectively, and this condition is retained in some of the adult tissues such as the nervous system.

Originally, the germ line of *Miastor* was interpreted as polyploid (i.e., octoploid),

and this conclusion seemed to be strengthened when it was found that in another cecidomyid, *Taxomyia taxi*, whose haploid number is 4, the germ-line nuclei contained 40 chromosomes, which was interpreted at that time as a decaploid condition; in *Taxomyia* all the chromosomes are so nearly alike in size and shape that it is not possible to distinguish them cytologically.

Studies on another cecidomyid, *Monarthropalpus buxi*, carried on at Cold Spring Harbor during the months of April and May 1947 have, however, rendered the hypothesis of germ-line polyploidy untenable for that species and hence unlikely in the case of other Cecidomyiidae. It now seems more probable that the germ line contains a number of "extra" chromosomes which are not represented at all in the soma, rather than that the somatic chromosomes are simply present in the polyploid condition in the germ line. If this is so, the fact that in *Miastor* and *Taxomyia* the number of chromosomes in the germ line is a multiple of the haploid

number may be merely a coincidence. In future we shall refer to the chromosomes which are present in both germ line and soma as S chromosomes, the "extra" chromosomes which are destined to be eliminated from the soma being referred to as E chromosomes.

SEX DETERMINATION IN THE CECIDOMYIDAE

In *Miastor* and *Oligarces* (subfamily Heteropezinae) and *Mycophila* (subfamily Lestremiinae), pedogenetic reproduction occurs, and has even become the main method of multiplication, sexual generations occurring only at long intervals in nature. Under conditions favorable for growth of these species (which are all fungus feeders), the larvae become sexually mature without undergoing pupation and give rise by parthenogenesis to broods of larvae, which live at first as internal parasites of their own mother, eventually emerging from her dead body to feed for a while on fungal mycelium before entering the reproductive phase. In this type of reproduction only females are produced, and no adult midges ever appear. Under unfavorable conditions, however, "sexual" larvae are produced, and these pupate and develop into adult midges before becoming sexually mature; both males and females are produced, and mating must take place before oviposition.

It had earlier been shown that the pedogenetic reproduction is a true parthenogenesis: the larval ovaries mature precociously and development of the eggs takes place within the maternal body. These eggs undergo only a single maturation division, which is an ordinary mitosis. In *Miastor*, 36 chromosomes are subsequently eliminated from the somatic nuclei. Thus all these larvae have a diploid soma and all are females. "Sexual" larvae arise by pedogenesis, in the same way, but

are of two kinds, males and females. In the embryonic condition they can be distinguished from pedogenetic embryos only by the fact that some of them (the males) have 6 instead of 12 chromosomes in their somatic nuclei.

Recent work on *Taxomyia* and *Monarthropalpus* has shown that these species (which do not reproduce pedogenetically) have 6 chromosomes in the male soma, 8 in the female soma. Thus they have not established a condition of somatic haploidy such as exists in the male *Miastor*, but their males may be described as somatically semihaploid, since they are haploid for two out of four chromosome pairs. Alternatively, we may designate them as having a complex sex-determining mechanism: X_1X_2O (σ), $X_1X_1X_2X_2$ (ϕ). Apparently, in all cecidomyids, sex depends on the number of chromosomes eliminated from the soma during the cleavage divisions, the number in the male and female germ lines being always the same. This condition is very reminiscent of that found in *Sciara* by Metz and his collaborators. Whether genetic factors influence the elimination process, so that a genetical difference exists between male and female embryos before elimination has occurred, is not known, but some species of cecidomyids which have not yet been studied cytologically are known to produce unisexual progenies.

In *Miastor* the elimination of the E chromosomes takes place during the third and fourth cleavage divisions. In male larvae 6 of the 12 S chromosomes must also be eliminated during cleavage, but it is not known whether or not this elimination takes place at the same time as the elimination of the E chromosomes. In *Monarthropalpus*, where we have made a detailed study of the elimination process, it takes place at the fifth cleavage division, that is, when there are 16 nuclei in the egg. Four of these nuclei, at the posterior

pole of the egg, do not divide at this division and apparently do not undergo the elimination process; they are the pole-cell nuclei, which will give rise to the germ line. The other 12 nuclei all pass through the elimination division synchronously. The total number of chromosomes present before elimination has not been determined with complete certainty, but is 50 ± 2 . In the elimination divisions only 8 of these chromosomes (in female embryos) split and pass to the poles; the rest fail to divide normally and remain in the equatorial region of the spindle. Thus each elimination division gives rise to two nuclei, with 8 chromosomes each, and a mass of "eliminated" chromosomes, which remains in the yolk cytoplasm for a long while, becoming gradually fragmented into smaller masses as the embryo develops.

It is not yet clear whether or not elimination follows the same course in male embryos, two S chromosomes being eliminated along with the E chromosomes at the fifth cleavage division. It is at any rate certain that two S chromosomes are eliminated in male embryos at some stage.

SPERMATOGENESIS IN THE CECIDOMYIDAE

Previous studies had shown that in *Mastor* and *Taxomyia* the sperm carries only a haploid complement of S chromosomes, all the E chromosomes being eliminated at the first meiotic division. Thus, in these species, the egg must be expected to carry all the E chromosomes, but this point has not yet been confirmed by direct observation on the meiotic divisions in the egg. There is no chromosomal pairing in the spermatogenesis of these species, and hence no possibility of crossing over in the males.

In *Monarthropalpus*, however, the spermatogenesis is of a somewhat different type. During the prophase of the first meiotic division there are two visibly dif-

ferent kinds of chromosomes in the nucleus: "condensed" ones, which form a crescent-shaped mass of dark-staining bodies to one side of the nucleus, and "diffuse" ones, which are distributed throughout the remainder of the nuclear cavity. At the first meiotic division a spindle is formed, which may be regarded as bipolar, although its two poles are different in nature, one being "active" during the ensuing division, while the other is "passive." As the division approaches, the "condensed" chromosomes become attached to the "active" half of the spindle, while the "diffuse" ones, which are thinner and stain rather faintly, remain in an unoriented tangle at the "passive" end of the spindle. The "condensed" chromosomes are definitely 28 in number and have a considerable range in size, the largest elements being about five times the length of the smallest.

As anaphase proceeds, the condensed chromosomes pass to one pole, the diffuse ones to the other. The latter have not been actually counted, but if there are 50 chromosomes in the germ line and 28 of these are in the condensed group there should be 22 in the diffuse group.

The result of the first meiotic division, therefore, is the production of two kinds of cells, one kind with 28 condensed chromosomes, the other with 22 (?) diffuse ones. The former pass through a second division, which is a simple mitosis, and the resulting spermatids develop into mature sperms; the cells with the diffuse chromosomes do not divide again, and simply remain in the testis as "residual cells" without forming sperms.

The sperms of *Monarthropalpus* thus transmit 28 chromosomes. Since the haploid number is 4, these presumably comprise 4 S chromosomes and 24 E chromosomes; but there are no peculiarities of appearance or behavior which would en-

able one to recognize the S chromosomes at this stage. The fact that the 28 chromosomes are of very different sizes precludes the possibility that the E chromosomes are simply duplicates of the S chromosomes (which are all approximately the same size) and excludes the hypothesis of germ-line polyploidy, so far as *Monarthropalpus* is concerned.

SALIVARY-GLAND CHROMOSOMES IN THE CECIDOMYIDAE

Preliminary studies on the salivary-gland chromosomes of a number of Cecidomyiidae were carried out during the summer of 1947. It was found that the general anatomy of the gland varies considerably in the different genera, and that this involves corresponding variations in the cytology of the nuclei. In some Cecidomyiidae the salivary gland is of a simple type, as in *Drosophila* or *Sciara*, whereas in others it may have a large basal reservoir or a pair of "supergiant" cells, very much larger than the ordinary "giant" cells of the gland proper. Both polytene and endopolyploid nuclei occur, and the two types may be found in different regions of the same gland. The following are the main conditions that have been found:

1. Gland simple; all nuclei endopolyploid (not polytene) *Miastor*
2. Gland simple; all nuclei polytene *Camptomyia* sp.
3. Gland with basal reservoir; nuclei of reservoir polytene, those of gland proper endopolyploid *Dasyneura affinis*
4. Gland with basal reservoir; nuclei of reservoir and of gland proper polytene *Contarinia canadensis*
5. Gland with two supergiant cells; nuclei of supergiant cells and of gland proper polytene *Cecidomyia serotinae*

6. Gland with one supergiant cell; nuclei of gland proper polytene, those of supergiant cell showing a combination of polyteny and endopolyploidy *Lestodiplosis* spp.

A number of unusual cytological conditions were found in some of the species studied. In *Camptomyia* sp. one of the four chromosomal elements in the salivary-gland nuclei is very much thicker than any of the others and shows peculiar properties. In *Dasyneura affinis* and *Contarinia canadensis* two of the four chromosomal elements bear nucleoli, whereas the other species have only one nucleolar element in the salivary-gland nuclei. Many species of Cecidomyiidae show two different kinds of heterochromatin in their salivary-gland nuclei, "compact" and "diffuse." The nucleoli always arise from diffuse heterochromatin, never from regions of euchromatin or compact heterochromatin. With the exception of one species of *Lestodiplosis* previously studied, no individuals heterozygous for inversions have been found in any of the species of Cecidomyiidae investigated.

GENERAL SUMMARY AND INTERPRETATIONS

The chromosome cycle of the Cecidomyiidae is radically different from that of all other animals hitherto studied, but its genetical implications are by no means clear yet. Basically, all the genera investigated have the same type of cytogenetic mechanism, but *Monarthropalpus* differs from the other genera previously studied in that a considerable number of the E chromosomes is carried by the sperm (in *Miastor* and *Taxomyia* the sperm transmits only a haploid set of S chromosomes).

The significance of the E chromosomes is obscure. In any particular species they seem to be constant in number, so that

there is no reason to believe that they are genetically inert to the same extent as the "limited" chromosomes of *Sciara* or the B chromosomes of maize. It might be suggested that they contain genes which function only in the germ line and up to the time of elimination in the soma (i.e., during the first few cleavage divisions); but it is difficult to believe that their role is so restricted. It is possible that the proteins and nucleic acids of the eliminated chromosomes are made use of as raw materials for the synthesis of S chromosomes in the cleavage nuclei, their role being similar to that postulated by Painter (1940) for the chromosomes of the nurse cells, which also become absorbed into the egg. But since the "nurse-cell mechanism" for supplying materials for the synthesis of cleavage chromosomes appears to be well developed in all the cecidomyid eggs that we have studied, it is difficult to see what advantage a second mechanism performing the same function would have. Furthermore, if the functions of the E chromosomes lacked genetical specificity, one would hardly expect them to be so constant in number (the "limited" chromosomes of *Sciara* spp. vary both in size and in number from one individual to another and are totally absent in some species of the genus). It therefore seems probable that the E chromosomes of the Cecidomyidae are not genetically inert and, furthermore, that they possess genetical specificity. It is possible that their genes do not cease to function when elimination occurs, but that they on the genetic products to which they give rise may persist for a considerable time in the somatic

tissues of the embryo or larva, exerting a delayed effect similar to the "maternal effects" now known in the genetics of many species of organism. Such a suggestion is obviously only tentative and cannot be tested until genetical work has been performed on some species of cecidomyid. Genetical studies are obviously impracticable on gall-making species such as *Taxomyia taxi* and *Monarthropalpus buxi*, which have only one generation per year, but might perhaps be attempted on one of the fungus-feeding or predaceous species, which breed rapidly.

Like *Drosophila*, the cecidomyids lack chiasmata in the males. Whether chiasmata occur in the females, and if so whether they are found only in the S chromosomes or also in the E chromosomes, is still undetermined; preliminary studies on the oögenesis of *Monarthropalpus* did not yield a definite answer to this question.

Whatever the precise genetical significance of the peculiar chromosome cycle of the Cecidomyidae, it is clearly one which is successful in an evolutionary sense, since the group constitutes one of the largest families of the Diptera (a minimum of 900 species have been described from the United States alone, in spite of the fact that there have been very few students of the group). Furthermore, the Cecidomyidae have been able to "colonize" the most diverse habitats, some species being fungus feeders and others gall makers, while a large number are predators on mites or other insects.

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SPECIAL PROJECTS: BIOLOGICAL SCIENCES

ROSS G. HARRISON, Osborn Zoological Laboratory, Yale University, New Haven, Connecticut. *Studies in experimental embryology.*

The grant from the Carnegie Institution has been applied toward the salary of a research assistant, who has been engaged chiefly in making additional models of the regenerating brain and in counting mitotic figures in these brains for comparison with the normal. A considerable amount of time had to be spent in the study of additional cases in order to obtain statistically significant results. This work is now completed and in type for publication in the October 1947 number of the *Journal of Experimental Zoology*. A résumé of the results follows.

Wound healing and reconstitution of the central nervous system after removal of parts of the neural plate. In the course of experiments designed to study the effect of absence of certain portions of the central nervous system on the differentiation of its associated ear vesicles, interesting observations on the regulation and restitution of the nervous system itself were made. The experiments concern regeneration in the brain after removal of portions of the neural plate in the early neurula stage in *Amblystoma punctatum*. The variants include excision of one lateral half and both halves of the presumptive hindbrain, either with or without underlying mesoderm and with the wound covered by grafted ectoderm or left uncovered; also cases in which a lateral half of the entire brain was taken without mesoderm and the wound covered. There are only minor differences in the healing and early behavior of the wounds in the various experiments.

After removal of one-half the hindbrain region of the neural plate, the remaining neural fold develops normally but inclines

across the median plane until it reaches the ectoderm of the opposite side, with which it then fuses. Being thus cut off from the exterior, the nervous tissue in the region of the operation is left as a half-tube, closed by neural crest derived from one side but later distributed to both sides. When the underlying mesoderm is left in, an equal distribution of the neural crest is facilitated and the visceral skeleton is normal in a large majority of cases. When the mesoderm is removed, the movements of the neural crest are often interfered with and the visceral skeleton on the side of operation is likely to be irregular and defective.

After the neural crest moves out, the neural half-tube closes, either directly by the two margins coming together, or indirectly by the formation of a lamina, extending from each border and ultimately closing off the central canal by a thin epithelial curtain. More frequently this appears to be mainly the product of the ventral border. After direct healing, the medulla is left usually with a thick roof and very small central canal throughout part of its extent, and dorsally a thin-roofed passage often interrupted but similar to the normal fourth ventricle. The fiber tracts do not develop normally in these cases. In the closure of the half-tube by the thin curtain, a sharp crease is formed in its wall at a varying distance from the ventral margin. This becomes the central longitudinal sulcus and marks the future ventral mid-line of the regenerated medulla. The thin curtain of epithelium which closes the tube lies at first ventral, and touches the notochord.

Through rotation on its axis the nerve tube is gradually righted and the sulcus even passes over to the defective side for a short distance. The material thus passed to the defective side is the original and principal contribution to its regeneration.

After bilateral extirpation of the presumptive hindbrain, the gap between mid-brain and spinal cord is not filled in.

After extirpation of an entire lateral half of the brain region of the neural plate, regeneration takes place likewise from the opposite side, although a minimal amount of material may come from the spinal region, since the cord in such cases is somewhat thinner on the defective side for some distance into the trunk region. Eyes regenerate from across the mid-line in all the cases in which a lateral half of the fore-brain is removed. The retinal layers are complete, but the vitreous body is very defective and no lens has been found.

Further augmentation of the original contribution from the opposite side takes place through hyperplasia, which leads to a mean relative restitution value of 71 per cent by the time the yolk is resorbed. The hyperplasia is significantly greater

when the underlying mesoderm is intact than when it is excised. That there is a genuine hyperplasia is shown by the excess weight of the two sides of the regenerating nervous system over the weight of one side of the corresponding part in the normal control, amounting to a mean of 152 per cent in four hindbrain operations and 167 per cent after removal of the entire half-brain. The more rapid cell division which produces the hyperplasia does not begin until some time after the operation, but it persists in a diminishing degree until the larva begins to feed, at which time in the hindbrain of the normal control it has come almost to a standstill.

A deficiency in the hindbrain probably also stimulates greater mitotic activity in more distant parts such as the telencephalon. The figures here are, however, not highly significant, and further investigation is required.

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DIVISION OF HISTORICAL RESEARCH

Cambridge, Massachusetts

A. V. KIDDER, *Chairman*

Success in archaeology, as in war, depends to a large extent upon an effective intelligence service and readiness to seize upon and exploit the "breaks." This is strikingly illustrated by the events of the past season's field work, during which information given by friends of the Division and at once followed up led to two of the year's three most rewarding undertakings.

First among these, perhaps indeed the single most important discovery ever made in the Maya field, resulted from word sent in by Mr. Giles G. Healey, who has long been interested in the Division's activities. In the winter of 1946 Mr. Healey penetrated the rough and practically unexplored jungle west of the Rio Usumacinta in Chiapas, Mexico, to photograph the primitive Lacandon Maya for a documentary film on Maya antiquities and the present-day Indians, which he is making for the United Fruit Company. Having with difficulty gained the confidence of the Lacandon, who are suspicious of all whites and are particularly loath to have them see the ancient temples at which they still conduct ceremonies, he was led by them to a small group of ruins three days' journey from the river. On entering one of the buildings, he was astonished to see that its three vaulted rooms were covered from floor to capstones with brilliant mural paintings.

Mr. Healey notified the Division of his find as soon as he was out of the bush, and at our request returned in July, accompanied by the Division artist, Sr. Antonio Tejeda. On the latter's report that the paintings far surpassed anything hitherto known, a party fully staffed and

equipped to make copies and photographs, financed by the United Fruit Company, and led by Mr. Karl Ruppert, spent six weeks at Bonampak (Maya for "Painted Walls"), as the site has been named by Dr. Morley.

The murals depict processions, ceremonies, warfare. The human figures, nearly life-size, are executed with extraordinary naturalism. Costumes, ornaments, weapons, and musical instruments are reproduced with remarkable fidelity and in great detail. There are long hieroglyphic texts. The walls of this forgotten little temple have yielded fuller data on many aspects of Maya civilization at the height of the Classic period than one had dared hope would ever be recovered. Mr. Ruppert's account of the expedition, with description of the paintings and of the very fine sculptures that also came to light at Bonampak, appears in the body of this report.

The second important find of the season can be traced back to the eruption of the volcano of Santa Maria in 1902, which covered the neighboring slopes from the highlands to the Pacific coastal plain with a meter of white ash. The region is one of the principal coffee-producing areas in Guatemala, but to set out the coffee trees it is necessary to dig through the ash and well down into the underlying soil. Sr. Vitalino Robles, of Quetzaltenango, owns a plantation there, the Finca El Paraiso, which is indeed a veritable archaeologist's paradise. Several years ago, in the course of planting, his workmen uncovered a series of stone slabs. Sr. Robles, an ardent amateur archaeologist, had the area cleared

of ash and, digging under the slabs, came upon a large cache of pottery. Always a most helpful co-operator with the Division, he halted work and sent word to our office in Guatemala City. Sr. Cesar Tejeda went to El Paraiso and assisted in removing the vessels, many of which were of plumbate pottery. This ware is of much archaeological significance because it was very widely disseminated in trade throughout Mesoamerica. It has been the subject of intensive study by Miss Anna O. Shepard (Publication 573). The El Paraiso plumbate proved to be of a type not previously known. For this reason it was desirable to obtain more material; in February Mr. E. M. Shook and the Chairman, at Sr. Robles' invitation, carried on further excavations.

The digging revealed the fact that the pottery cache had been made in a large, low mound, its contours masked by the heavy layer of volcanic ash. On widening and deepening the original Robles pit, we encountered a rectangular tomb, its closely fitted wall and floor slabs painted red. It held two skeletons accompanied by much plumbate pottery and jade. In another part of the mound were burials in great pottery urns.

While work at the mound was in progress, Mr. Shook investigated another outcropping of stone slabs at a spring in a near-by ravine. These turned out to be the outer edge of an extensive pavement which, sloping upward, ended at a narrow masonry-walled, slab-roofed passage that led into the side of the ravine. It was at first believed that this must be the entrance to a tomb, but when it was followed to its end it proved to open into a round chamber, 8 m. in diameter, with two encircling benches and a central pit full of ashes and burned stones, evidently a communal sweat bath. It is of an entirely new type and was probably of ceremonial sig-

nificance, for in clearing the frontal pavement we found enormous quantities of fragments of fine plumbate vessels doubtless ritually broken. Mr. Shook's report on the El Paraiso work is appended.

Also adding significantly to knowledge of Maya archaeology were several very important tombs opened by Mr. A. L. Smith in the Department of Quiche, Guatemala, where in 1946 he had excavated a tomb of the Early Classic period in one of a group of mounds in the outskirts of the highland Indian village of Nebaj. Facing that mound was another. Surmising that this might contain other interments, he returned to Nebaj in 1947 and became involved in a most difficult but most highly productive piece of excavation. The mound's frontal platform proved to hold a series of tombs, altars, and ceremonial caches so stratified that their age, relative to one another, could surely be determined. The pottery vessels, incense burners, alabaster and marble vases, pyrite mirrors, gold and copper ornaments, and magnificent carved jades recovered illustrate the development of local arts over a period of some seven centuries; they prove that Nebaj was long the seat of an unexpectedly rich and flourishing community; and they indicate that a lively trade was maintained with the great centers on the Rio Usamacinta. Mr. Smith's report appears below.

The foregoing were the highlights of a most successful season, which included various other field activities.

A. L. Smith, before going to Nebaj, continued his survey of the northern highlands, mapping, noting, and photographing ruins in the Department of Baja Verapaz. Later he visited a number of sites in the Nebaj-Aguacatan-Sacapulas area in the company of Miss Tatiana Proskouriakoff, who gathered material for reconstruction drawings of sites and buildings of the sort contained in her *Album of Maya*

architecture (Publication 558). At Nebaj, Miss Proskouriakoff undertook the essential and in this case particularly difficult task of recording, on plans and sections, the exact location of tombs, caches, and architectural features as they came to light in the excavation of the mound.

E. M. Shook inaugurated a southward-heading survey of archaeological sites on the Pacific slope and coastal plain. He commenced operations in January, excavating at mound groups near Ayutla, on the Mexican border. At the same time Dr. Philip Drucker, of the Smithsonian Institution, began a similar survey on the Mexican side and worked northward. Dr. Drucker and Mr. Shook are keeping in close touch with each other and their combined efforts will open up a region hitherto almost completely neglected and one which not only was densely populated in ancient times, but was certainly always a highway for migration and commerce. Very interesting finds are to be expected.

Shook's investigation at Ayutla was interrupted by the opportunity to dig at Finca El Paraiso, which is also in the zone of his projected survey; and just as that excavation was finished, the United Fruit Company sent word of discoveries at Tiquisate, still farther south on the coastal plain, which had been made in breaking new land for banana farms. Given every facility by the Company, Shook spent several weeks at Tiquisate putting in test trenches and studying material that had come to light during the developmental operations.

The Chairman, as stated, worked with Shook at El Paraiso. He visited A. L. Smith's diggings at Nebaj and made several trips to Huehuetenango, in western Guatemala, where the United Fruit Company is carrying on an extensive project of excavation and repair at the ruins of Zaculeu, the ancient capital of the Mam

Maya. Close touch is being kept with this work, which is yielding much information that bears on architectural and ceramic problems of interest to the Division. The technical aspects of the project are being handled by Messrs. S. H. Boggs and A. S. Trik, both former members of the Division staff; this year Mr. Gustav Strömsvik of the present staff was given leave to supervise the restoration of the Zaculeu ball court.

Another archaeological undertaking that keys well with the Division's program is an examination by Dr. Robert Wauchope, also formerly with the Division, of Guatemalan sites occupied at the time of the Spanish conquest. The work is being done by the Middle American Research Institute of Tulane University.

An interesting and important development has been the establishment in Guatemala City of a very fine new anthropological museum. Mr. R. E. Smith, the Division's local representative, has been acting as chairman of the government's committee on planning and installation. This has occupied a large share of his time during the year, an activity justified by the fact that the museum will house the Division's great collections from Uaxactun, Kaminaljuyu, Nebaj, and other sites, as well as by the fact that the ample storage space now become available will permit transference from our office to the museum of the large and extremely valuable lots of potsherds gathered by us from all parts of Guatemala. In order to have more ready access to these materials, the office of the Division has been moved from downtown Guatemala to a building close to the museum.

The Division office has continued to serve as headquarters in Guatemala City for scientific workers from other institutions. This year it has been so used by Dr. L. C. Stuart, of the University of

Michigan, who is making a herpetological survey of the Republic; by Dr. Wauchope, of Tulane University; and by Dr. T. Dale Stewart, physical anthropologist of the United States National Museum. Dr. Stewart's work, under a grant from the Department of State, has been of great value to us. In past years, abundant data have been gathered on the bodily make-up of the Yucatecan Maya, but no comparable information has been available regarding the various Maya-speaking groups of the highlands. Dr. Stewart measured, photographed, and blood-tested series of men and women at Solola and Patzum. He also studied the considerable amount of skeletal material accumulated by the Division in past years, as well as that found during the Zaculeu excavations. He was supplied with a Division car and greatly aided by native interpreters put at his disposal by Professor Antonio Goubaud, Director of the Instituto Indigenista Nacional. Professor Goubaud's assistance furnishes a further example of the hearty co-operation the Division has always received from the governments of Guatemala and Mexico, the latter having granted duty-free entry of the equipment and supplies necessary for the Bonampak expedition and having delegated a staff artist of the Instituto de Antropologia e Historia, Sr. A. Villagra, to accompany the party and work with Sr. Tejeda. For these and many other favors throughout the years, the Division is under deep obligation to Dr. Alfonso Caso, former Director of the Instituto; to Arq. Ignacio Marquina, its present head; and to Dr. Eduardo Noguera, Director of the Instituto's Department of Pre-Hispanic Monuments.

In the field of Maya linguistics, Dr. Norman McQuown, by arrangement with the Department of Anthropology of the University of Chicago, is giving half his time to study of the great mass of material

gathered by the late Dr. Manuel J. Andrade. In December 1946 he made a trip to the Huastec Indians, a tribe in the Mexican state of Veracruz, who, although speaking a Maya language, are now, and apparently long have been, culturally quite distinct from the main southern group of the Maya.

Desk activities of the Division staff have also gone forward. Dr. S. G. Morley has been engaged in preparation of guidebooks to Chichen Itza and Uxmal, and has made further progress on a dictionary of Maya hieroglyphs. His large and fully illustrated book, *The ancient Maya*, was published during the year in English by the Stanford University Press and in Spanish by the Fondo de Cultura Economica in Mexico. Its wide sale, calling at once for a second printing, indicates how satisfactorily it fills the long-felt need for a work on the Maya suitable for the general reader. Dr. H. E. D. Pollock continued working up the great amount of data on the architecture of the Puuc area in Yucatan gathered by him and Mr. Shook in the years before the war; Mr. Karl Ruppert, before leaving for Bonampak, was occupied with architectural materials collected last year at Chichen Itza. Miss Tatiana Proskouria-koff devoted herself to the intensive study of Maya sculptural art; Mr. J. E. S. Thompson, to that of Maya hieroglyphic writing. Under part-time arrangements with the Peabody Museum of Harvard University and the United Fruit Company's Zaculeu Project, Dr. J. M. Longyear worked on the pottery he obtained at Copan in the winter of 1946; Mr. Stanley H. Boggs, on that from his excavations for the government of Salvador at Tazumal. Mr. E. H. Morris continued preparation of reports on finds of former years made in Arizona caves occupied by early Southwestern agricultural peoples. Miss Anna O. Shepard completed a monograph on plum-

bate pottery and a paper on symmetry in ceramic decoration, both of which are now in press.

Mr. R. L. Roys continued his research on Maya-language documents of the early colonial period. Dr. F. V. Scholes' work on Yucatan in the sixteenth century goes forward, with the assistance of Miss Eleanor B. Adams, at the University of New Mexico, where he is now Dean of the Graduate School. Dr. Robert S. Chamberlain has completed monographs on the conquest of Yucatan and of Honduras. He has accepted a post as Associate Professor of History at the University of Miami. Dr. Sol Tax, of the University of Chicago, has given half time to preparation of reports on the Quiche and Cakchiquel Indians of Guatemala; Sr. Alfonso Villa R., full time to data gathered in former years on the Maya-speaking tribes of Chiapas. The completion of the foregoing historical and ethnological researches will bring to a close the activities of the Division in these fields. Under the respective direction of Dr. Scholes and Dr. Redfield, they have done much to throw light upon the findings of the archaeologists and to render understandable the conditions existing today in Mexico and Guatemala.

As of June 1, 1947, Miss Eleanor W. Ritchie resigned to be married, thus terminating her long, faithful, and effective service as Division secretary.

BONAMPAK EXPEDITION

KARL RUPPERT

Early in 1946 Mr. Giles G. Healey, employed by the United Fruit Company to make a photographic record of the Maya, past and present, was in the eastern part of the state of Chiapas, Mexico, filming some groups of Lacandon Indians, and was directed by them to the site of Bonampak. Here he noted some remark-

ably well preserved paintings on the walls and vaults of the only standing three-chambered building.

On his return from the bush Mr. Healey reported the find to the Chairman of the Division, who at once arranged for Sr. Antonio Tejeda, Division artist, to go to Bonampak. In July Mr. Healey and Sr. Tejeda spent five days at the site. The paintings, as shown by the sketches made at that time, were so remarkable and so important that it was considered imperative to send an expedition for their complete recording.

In the winter of 1947 such an expedition was undertaken, financed by the United Fruit Company and directed by Carnegie Institution of Washington. Personnel included: Karl Ruppert, in charge; Gustav Strömsvik, engineer; J. Eric S. Thompson, epigrapher; Antonio Tejeda, artist (all of Carnegie Institution); Giles G. Healey, photographer, United Fruit Company; and Agustín Villagra, artist, Instituto Nacional de Antropología e Historia, Mexico.

Mr. Strömsvik reached Bonampak January 31, having gone ahead to arrange transportation and establish camp. Messrs. Healey and Thompson arrived February 15 and returned to Tenosique February 28, Mr. Thompson returning to the States, and Mr. Healey again leaving for the ruins on March 6. The remainder of the party, proceeding by plane to Agua Azul on the Usumacinta River and thence by mules, reached the site March 17.

Bonampak lies about 25 leagues south and slightly east of the ruins of Yaxchilan at an elevation of 400 m. In this area Mr. Healey has found a number of previously unreported ruins. The site is relatively small, compact, and carefully laid out, with a main plaza measuring 90 m. by 110 m. and surrounded on three sides by low mounds. The fourth side is defined by a natural hill, 43 m. high, artificially

terraced, up which, from plaza level, a broad flight of six steps rises to a wide landing on which were found Stelae 2 and 3 and their associated altars. From this landing the stairway, now wider by 12 m., continues to a second landing on which are seen two standing buildings. Building 1, containing the wall paintings, is of three rooms; the other is a single-chambered structure. A third platform or landing 14 m. higher supports six standing buildings, each with a single chamber. On top of the hill, reached by a well defined stairway, are a number of artificial mounds formed by the collapse of structures. Though the eight standing buildings are in a surprisingly good state of preservation, large trees growing on the roofs will hasten their disintegration.

The buildings in most cases rise from a simple plinth. The lower wall zones are plain; the masonry is of blocks with some slabs. The upper zones are faced with small, regular slabs, rise with a batter, and often show traces of stucco decoration. Only one structure has roof ornamentation; it consists of a perforated roof comb formed by a series of seven transverse walls, 4 m. in height. The vaults show much variation: simple soffit slopes, interrupted slopes, and stepped. The lintels of all standing buildings are of stone, four of them sculptured.

Only one of the five stelae found in the plaza is sculptured. This monument, now broken, had a height of 5 m., width of 2.60 m., and thickness of 20 cm. It carries an Initial Series date of 9.17.?.?.? and is further sculptured with a single human figure. Also in the plaza are a number of plain altars, circular and rectangular, one of the latter resting on short wedge-shaped legs. A crudely carved jaguar figure, 2.18 m. long, lies in the northeast sector of the plaza unassociated with any structure. The two stelae and two altars

on the first landing of the terraced hillside are beautifully sculptured. One of the buildings on the upper landing contains a plain stela; inside four buildings are plain, slightly tapering, columnar altars.

Building 1, with three chambers, contains the wall paintings. The building has an over-all length of 16.50 m. and width of 4.12 m. Its exterior construction is similar to that of other buildings at the site. In the upper zone there remain traces of stucco decoration and niches containing seated figures. The lintels are sculptured. A wide bench is built against the end and back walls of each room; from an offset at the spring line, the vault rises in a slope with a single interruption. Beam holes, in pairs, are seen at two levels.

The recording of the paintings in Room 1 constituted the major project of the expedition. The condition in which the paintings were found and the preparation necessary before they could be copied is described by Sr. Tejeda:

Growing out of the top of the building were great trees whose roots pierced the masonry. In some parts where they have rotted owing to the action of time or to the separation of the stones, the roots have permitted a constant infiltration of water, which has deposited on the stucco walls a calcareous sediment that in some places is so thick that it is impossible to perceive what kind of decoration existed. This destructive action is evidenced sometimes by petrified bubbles, and sometimes by a calcareous layer, just as though the walls had been painted white. In some places the infiltration is so constant that it has washed away the paintings, making recovery impossible. The humidity has also favored the growth of fungus, green and black. A factor that has contributed greatly to the destruction, especially where the walls are vertical as are the divisions between rooms, is the droppings of a great many bats which have found a comfortable lodging in the upper part of the vault. Finally, it is believed that the most dangerous element of

destruction is the capillary roots that have entered between the wall proper and the plaster surface that carries the paintings. The damage may be seen in places where the roots have wedged out and displaced the painted stucco, now lying on the floor, almost pulverized.

Sr. Villagra, who also made copies of the wall paintings, and Sr. Tejeda began the long and tedious task of cleaning the walls before starting to draw. To obtain greater transparency of the calcareous coating, once we had removed the thickest part, we applied water, but succeeded only in vaguely enlivening the colors. It occurred to Sr. Tejeda to try kerosene, and the result was a great success, as it was possible to observe in the paintings details which previously were not known to exist. The kerosene is applied with a brush, and the action endures approximately eight or ten hours, after which it disappears by absorption and volatilization. It does not hurt the colors, and serves temporarily to impede the formation of fungus.

Never before had such a wealth of Maya wall paintings been available, nor had anything been found comparable in subject matter, detail, and execution. On the walls and vault of this one room thirty-four human figures are portrayed. In the center of the back wall are three figures wearing elaborate costumes and ornate headdresses. To their left is a group of musicians, some blowing long trumpets, some carrying gourd rattles, others carrying turtle shells which are struck or rasped with a forked stick. One man stands behind a vertical drum with a skin stretched over the upper end. The figures to the right bring offerings or are in positions of adoration. The first band on the vault is of hieroglyphs and groups of human figures; above this, on the vault and capstones, are large bold masks.

In the time spent at the site the artists were able to copy the paintings in only one chamber. Although those in the middle

room were not recorded, some of the scenes, such as that in which blood is seen dripping from the ends of men's fingers, or those showing processions and probably battles, are of such interest and excellent draftsmanship that their value is equal to if not greater than that of the paintings copied this past season.

GUATEMALA HIGHLANDS

EDWIN M. SHOOK

Mr. Shook resigned from his position with the United States Government and returned to the Division in August 1946. Early in October he began preparation for field work in the southwestern highlands and on the Pacific coast of Guatemala. An intimate knowledge of most of this area and the contiguous region of Chiapas, Mexico, had been gained during three years' service on the government's Cinchona Procurement Program. As complete a record as possible, under the circumstances, had been made of the archaeological remains throughout the zone. The information thus gathered showed that the narrow strip of hot coastal plain from sea level to approximately 300 m. elevation had witnessed the ebb and flow of pre-Columbian Indian culture from the earliest horizons known in Guatemala to the time of the Spanish conquest. Sites ranging from small clusters to great groups of mounds, each over a kilometer in extent, line the banks of the many streams crossing the fertile plain. The site of Itzapa, just across the Mexican border in Chiapas, is typical of the large ruins. With a few exceptions, the remains above the 300-m. elevation on the Pacific slope of the cordillera are small and widely scattered. Tajumulco is typical of these sites. Not until the broad inland valleys and plateaus north of the volcanic mountain range are reached does one encounter ruins of con-

siderable size. An examination of private archaeological collections and surface sherd samples from southwestern Guatemala showed plumbate pottery to be most abundant down the Rio Cusulchima and Naranjo valleys, fanning out over the Pacific slope and coastal plain from these drainage systems.

The first activity of the field season was a reconnaissance of the northern half of the San Marcos Department and the Rio Cuilco valley of southern Huehuetenango, not only to search for the source of plumbate pottery, but to fill the remaining void in the archaeological picture of southwestern Guatemala. A suitable base of operations was established at the United States Government cinchona plantation, Finca El Porvenir, situated on the south slope of the Tajumulco volcano. The trip from El Porvenir to San Marcos and Tejutla was made by automobile on October 23. Thereafter, a ten-day circuit of 200 km. was made on foot and horseback to Sipacapa, San Miguel Ixtahuacan, Antigua Tutiapa, Cuilco, Canibal, Tectitan, Tacana, Ixchiguan, back to Tejutla, and then by car to El Porvenir. Over thirty minor sites were recorded. Each of the modern towns mentioned, with the exception of Ixchiguan, had one or more archaeological ruins within the town or on the outskirts. The most important zone appears to be the Cuilco valley, where remains occur at short intervals on both sides of the river; others are situated in tributary valleys and on spurs of the Sierra Madre directly above the Rio Cuilco. One well preserved hilltop site, Pueblo Viejo, 8 km. southwest of Sipacapa, has exposed masonry of cut semiblock and slab stones laid in mud mortar. At Chilipe, 7 km. south of Cuilco, a well defined open-end ball court was found, the only ball court seen on the trip. The previously known ruins of El Reparo, 10 km. below the town

of Cuilco, were visited and a large stone monument and urn burial discovered. The monument, carved in the round and depicting a full standing human figure, stood on the lowest step of the principal pyramid. The burial of a young adult was found below the top floor of the same pyramid in a large red ware urn with another pottery vessel inverted over the lower as a cover. Although surface sherds were examined and samples collected, no plumbate ware was seen at any site visited on the trip. This is of particular significance in the continuing search for the manufacturing center of this most widely traded Mesoamerican pottery.

The second part of the field season consisted of a series of excavations on the Pacific coastal plain paralleling the Guatemala-Mexico frontier. El Sitio, the first site investigated, is an enormous group of mounds formally arranged around plazas with monuments of plain columnar basalt. The ruins lie along the east bank of the Rio Gramal, a small tributary of the Rio Suchiate, 18 km. north of Ayutla, on the highway to Catarina and Malacatan. Five test pits were sunk: four through platforms and mounds from surface to sterile subsoil, the fifth on level ground at the north edge of the site away from ancient construction. This last test produced a mixed lot of material from two distinct occupations of El Sitio. The earlier belonged to the Middle Culture horizon contemporaneous with the Miraflores phase in Kaminaljuyu, whereas the later occupation occurred during the post-Classic period, as plumbate pottery was well represented. The burial of an important personage was found below the floor of a terrace or platform. A huge pottery urn covered by another inverted vessel contained the body, jade beads, and ornaments. Other burial furniture was on the outside, including a finely carved stone

scepter. The major occupation and greatest architectural activity took place at El Sitio during the Late Middle Culture period.

A small site, La Libertad, on the east edge of the highway, 14 km. north of Ayutla, was next investigated and proved to be contemporaneous with the late occupation at El Sitio. Plumbate sherds occurred in each level of the stratigraphic cut. Similar evidence was recovered at Santa Romelia, where a group of scattered mounds on both banks of the Rio Seco, 10 km. north of Ayutla, indicated a small village rather than a large ceremonial center like El Sitio. Again, plumbate was evenly distributed from top to bottom of the test cut and amounted to 30 per cent of all sherds. Here the results show that plumbate pottery served a utilitarian as well as a ceremonial purpose.

At Ayutla single small groups of mounds may be found anywhere on the plain between the Suchiate and Melendres rivers. During the leveling for a railroad siding, about 75 cm. of the ground surface was cut down and archaeological material equivalent to Santa Romelia and La Libertad was exposed. Just east of Ayutla on the west side of the Rio Melendres another major site, El Jobo, comparable in size to El Sitio and Itzapa, was discovered. Pyramidal mounds up to 15 m. in height and a multitude of lesser structures, arranged in an orderly manner around plazas, extend approximately 1 km. along the riverbank. A finely carved stela of the Itzapa style, and two urn burial accompanied by some forty pottery vessels were found in El Jobo. The burials and furniture belong to the Middle Culture horizon and are contemporaneous with the early occupation of El Sitio. Unfortunately the stela had been disturbed and broken in recent times and lay at the foot of a mound. An unsuccessful attempt was made to

locate its base and associate the stela with the ceramic material. The structure with which the monument was associated had been built during the early period, but surface sherds of plumbate also indicated that El Jobo had a more recent occupation. A small site, Buena Vista, just south of El Jobo and possibly an outlying group of that large center, produced from the central fill of a mound a large plumbate burial urn containing the skeletal remains of a child, and a beautiful jar of the same ware.

There are many archaeological ruins on the fertile strip of land from Ayutla to Ocos between the Rio Suchiate and the Naranjo. The major sites are Santa Clara, Los Limones, and La Zarca, 6, 10, and 13 km. respectively below Ayutla. Another plumbate burial urn containing an infant skeleton was found in a mound at Santa Clara, and a ball court of the open-end type was discovered.

On the Hacienda Los Limones there are two sites: one on the east bank of the Suchiate, the other on the west side of the Naranjo. The latter has a type of construction hitherto unknown on the Pacific coastal plain. The substructures consist of a hearting of sandy brown earth encased by masonry terrace walls of small, selected river-worn stones laid in lime mortar and finished with a heavy layer of excellent lime plaster. The lime was derived from sea shells; in many instances the unsuccessfully burned shells or their fragments appear in the mortar. Unfortunately the short stay at Limones produced no pottery to aid in the placement of this site in the cultural sequence.

La Zarca is a major site located on the east bank of the Suchiate. No excavations were undertaken, but a ceramic sample was obtained from the local farmers, who are constantly unearthing archaeological specimens during crop planting. The ma-

terial showed that La Zarca had the same occupational range as El Sitio and what appears to be a postplumbate period. Characteristic of this phase are red-on-cream ware tripod bowls with tall, birdhead-effigy feet. Some of these bowls have striations on the interior similar to grater bowls or *molcajetes* from late horizons in the Valley of Mexico.

The small, briefly investigated site of La Victoria, 17 km. south of Ayutla and 3 km. inland from the ocean, produced a relatively high percentage of solid, hand-modeled figurines of the so-called Archaic type, now assigned to the Middle Cultures. Again the presence of plumbate in the surface levels indicated a more recent occupation.

The third part of the field season, from late January to early March, was spent on Finca El Paraiso, a coffee farm on the Pacific slope at 1000 m. elevation. El Paraiso is located in the Chuva zone of the Department of Quetzaltenango, 10 km. by road north of Colomba. The owners, Srs. Vitalino and Benjamin Robles, during the course of coffee cultivation, have made important archaeological discoveries over a period of many years. The majority of the objects they found came from an insignificant-looking low mound on a level bench of land jutting out from the main mountain range. Undoubtedly, the mound was the principal structure of a small village occupied during Late Classic and post-Classic times. In the upper part of the mound the Robles found two gold disks associated with effigy plumbate pottery; in 1943, assisted by Sr. Cesar Tejeda, they encountered a cache of many vessels without metal at a greater depth. The specimens were made available to the Division for study, and a generous invitation was extended by the Robles to make further investigations in El Paraiso. Accordingly, Dr. Kidder and Mr. Shook

planned to devote from three to six days there, thoroughly recording all data. It actually required six weeks, so rewarding were the excavations.

A north-south trench was dug through the mound's center, disclosing its construction. It was an earth-and-stone-filled platform with vertical exterior walls heavily backed with waterworn boulders. The platform probably once supported a structure of perishable material. Within the platform was found a red-painted, stone-lined, richly stocked tomb sunk through subsoil prior to the platform's construction. It contained the skeleton of an adult seated cross-legged on the floor, backed against the north wall, facing south. Another human skeleton lay diagonally across the floor of the tomb. Around the dead, covering the available floor space, had been placed a wealth of furnishings; the tomb was then filled, and other offerings were piled in a heap above the closed tomb. This was the pottery cache discovered by the Robles in 1943. The tomb and cache contents included jade and shell beads and ornaments, obsidian lancets, an iron-pyrite mosaic mirror, nine pottery bells, three drums, one flageolet, one whistle, three figurines, nine spindle whorls, and over sixty-seven vessels. Plumbate was the most abundant ware found in this tomb.

Near the platform's center, 3.50 m. below the surface, another interment had been made before construction of the mound. Two large pottery urns, each containing an adult body, were found side by side, each covered by an inverted vessel. The furnishings, both inside and outside the urns, included jade beads and ornaments, small black polished pebbles, an iron-pyrite incrustated mirror, pottery spindle whorls, and vessels. Several of the latter are of plumbate ware. Many caches of one or more pots were found throughout the fill of the mound, some having

been put there during construction, others near the surface having possibly been buried after completion of the mound. We believe that the two thin gold disks and effigy plumbate vessels discovered by the Robles belong to the later of these caches.

West of the platform the land slopes sharply to a ravine called La Gruta, from the head of which issues a spring of cool, crystal-clear water. Carvings on natural rock outcrops and the abundance of potsherds led the Robles to investigate. They uncovered a line of flagstones and a rich deposit of sherds, and had the fortitude to resist further digging until our arrival. The flagstones proved to be those of a broad paved terrace facing the spring. A stone stairway descended to the terrace from the direction of the village site above. At a right angle to the natural slope of the ravine's north side, an underground passage, large enough to permit a short man to walk erect, led 7 m. into the hillside from the paved terrace. At that distance a stairway ascended to the interior of a circular structure somewhat resembling a Southwestern Pueblo kiva. It consisted of a central fire pit encircled by two flagstone benches, one above and set back from the lower, like seats of an amphitheater. The maximum inner diameter of the top bench was 5.65 m. The level of this bench averaged 1 m. below the soil surface prior to the 1902 eruption of Santa María volcano, which added about 1 m. of pumiceous ash to the Paraiso region. The fire pit of the circular structure was filled with broken metates and unworked boulders, all severely burned. The passage served as a drain as well as an entrance, as far as the terrace below, where a well made, stone-lined, slab-covered drain channeled the flow of water along one side of the terrace to the ravine. No conclusive evidence was

obtained on the use of the circular structure or on the method of roofing. It is believed to have been roofed and possibly to have served as a ceremonial or communal sweat bath. The ceramic material from La Gruta proved the contemporaneity of the circular structure and the village site at El Paraiso.

The fourth part of the field season, from mid-April through May, was spent in exploration and excavation on the lower coastal plain south of Tiquisate in the Department of Escuintla. Recently the United Fruit Company began clearing this area for new banana plantations, digging deep drainage canals and building roads, in the course of which work a wealth of archaeological material was exposed. Through the kindness of the Company officials and particularly the Tiquisate manager, Mr. A. L. Bump, the opportunity was offered the Division to investigate the area. Excavations were made on Ticanlu, Tacana, Zunil, and Toliman farms, and surface sherds collected at Las Trozas, Huisisil, Ixtepeque, and Pacaya. Many of the ruins bordered on a dry stream bed between the present Nahuallate and Naranjo rivers. If the stream dried up or radically shifted its course during the occupation of these sites, it must have had a profound effect on the inhabitants. The excavations in four of the ancient settlements along the dry stream bed proved that they flourished vigorously during the Early and Late Classic periods. Then activities abruptly ended and the area, at least that part investigated, was abandoned. No effigy or Tojil period plumbate or postplumbate material was recovered in the excavations or was seen in any of the private collections in Tiquisate. Prior to the Early Classic surge in Tiquisate, apparently a thinly scattered population inhabited the zone, as a small amount of Middle Culture material was found.

Diagnostic of this period are solid, hand-modeled figurines and certain forms of Usulután ware pottery.

During the field season, visits were made to Copán and Zaculeu to keep abreast with the work of others. Dr. Kidder and Mr. Shook briefly inspected the ruins of San Cristóbal, Department of Totonicapán, and Piedra Parada, Santa Isabel, Canchón, and Virginia, Department of Guatemala. They also began the recording of the immense Robles Collection of pottery and artifacts in Quetzaltenango. Mr. Shook continued compiling information on modern sweat baths and on the manufacture of archaeological counterfeits in Guatemala.

GUATEMALA HIGHLANDS

A. L. SMITH

The work carried on during the 1946-1947 field season consisted of the following activities: reconnaissance in the Departments of Baja Verapaz and Quiché; excavations at Nebaj, Department of Quiché; visiting various sites in the Departments of Huehuetenango, Baja Verapaz, and Quiché in order to gather material for reconstruction drawings.

During the first five weeks of the season's work, Mr. A. L. Smith, assisted by Sr. Cesar Tejeda, carried on archaeological reconnaissance in Baja Verapaz. Six sites were visited: Cahyup, Chuitinamit, Pichec, Toloxoc, Pachalum, and El Portón. Plans of these sites were made, individual buildings measured and photographed, architectural details recorded, and, where possible, surface collections of pottery recovered. The two most interesting ruins were Cahyup and Chuitinamit in the Rabinal area. Both of these are fortified sites of the conquest period situated on the crests of high hills on the north side of the valley of Rabinal, the former at its

east end, the latter northwest about 8 km. down the valley. At the time of the conquest the Spaniards attempted to conquer the valley of Rabinal, but were driven out, and it was not until after the Indian rulers at Cahyup and Chuitinamit were converted to Christianity by Las Casas and Father Angulo that the Spaniards finally occupied the valley.

The ruins of Cahyup lie about 2 km. north of the village of Rabinal. There are five groups. The main group crowns the top of a hill some 250 m. above the valley. The twenty-two structures that form this group are located in and around three plazas and consist of temples placed on high platforms, long single-room buildings with multiple doorways, and altar platforms. The single-room buildings form two or three sides of a plaza and face upon it; temple structures are placed in the plaza and are associated with one or more altar platforms. One of the most interesting structures at Cahyup is a large pyramid supporting two temples, each resting on its own platform. Two other groups are on hills to the north and northeast of the main group; the remaining two groups lie in the depression between the hills. Irregularly placed on the slopes leading down into the depression mentioned above are short terraces which undoubtedly once supported houses of perishable materials. A most unusual construction was found on a high hill about 1.5 km. north of the main group. This proved to be a solid, round masonry structure 2.40 m. high with five terraces rising to a flat top. It may have been used as a watch tower or signal post.

The ruins of Chuitinamit consist of eight groups extending along the top of a ridge about 300 m. above the valley. The general direction of the ridge is northeast and southwest. The groups are well separated so as to form definite units. With

the exception of two ball courts, a type of construction not found at Cahyup, the two sites have similar structures arranged in much the same way. The ball courts are of typical conquest site design, with end zones enclosed by high walls and stairways leading out at either end. One of the courts had never been completed. Southwest of the most northeasterly group, two high defense terraces protected the rest of the site from attack. The upper slopes of the ridge, close to the various groups, were dotted with house platforms. These, of which there were over 400, were small platforms of stone with a terrace in front of each. Both Cahyup and Chuitinamit have many well preserved standing structures that show a great deal of Mexican influence. A good example of this, which occurs at both sites, is twin temples standing on a common pyramidal substructure.

Pichec, another hilltop site, lies directly across the valley from Chuitinamit. It is a small group comprising a temple and altar and several low platforms. Toloxcoc stretches along a high ridge about 7 km. southeast of Rabinal. There is very little standing masonry left, just low platforms with post holes, small shrines, and considerable terracing. Pachalum is another hilltop site just east of San Jeronimo. Stretching along the crest of a hill about 300 m. above the Salama valley, it is a fairly extensive ruin of the type of Chuitinamit. The main plaza has a temple in its center and several altar platforms, and is bordered by long, low, one-room buildings. There is no ball court, but there are outlying platforms and terracing. Locally the ruins are known as "Pueblo Viejo," but as this term is often used for sites lying near villages, it seemed best to distinguish the site by calling it Pachalum after the hill upon which it rests. El Porton, a valley site, is on a national plantation about 1 km. out of San

Jeronimo on the road to Salama. There is no masonry showing here, only a group of mounds on three sides of a large plaza.

After leaving Baja Verapaz, Smith and Tejeda, accompanied by Miss Proskouria-koff, moved to Nebaj, Department of Quiche, where comfortable quarters in the local pension served as a base for the remainder of the field season. Most of the time at Nebaj was spent in excavating the frontal platform of a large mound in the main group of the ruins of Nebaj. This mound has the same shape as a mound facing it, in which, during the 1946 field season, Smith excavated a corbel-vaulted tomb of the Early Classic period. Leaving Tejeda to find the entrance of the passageway into a similar tomb, Miss Proskouria-koff and Smith visited other sites to gather material for reconstruction drawings.

The first ruin visited was Chalchitan, a valley site in the Department of Huehuetenango. Here the ball-court group, rather than the whole site, was chosen for investigation. In the Sacapulas area of the Department of Quiche the fortified hilltop site of Chutix Tiox and the valley site of Xolchun were selected. Throughout the season, when opportunity offered, other sites were visited for the same purpose: in the Ixil area of the Department of Quiche, the ball-court sites of Oncap, Huil, Tziquay (see pl. 1), Vicaveval; in the Rabinal area, Cahyup and Chuitinamit. In Sacapulas two tombs were found, one at Chutix Tiox, the other at a new site called Xolpacol, about 6.5 km. from Sacapulas on the road to Aguacatan. Unfortunately, both tombs had been robbed, but their shape could be determined; it proved to be very different from that of tombs found at earlier sites, Chutix Tiox and Xolpacol being of the late, conquest type. The tombs, which were in structures, had two chambers each, an inner circular one which was the tomb proper,

and a rectangular antechamber considerably larger in area. The two parts of each tomb were joined by a doorway blocked by a stone slab.

Returning to Nebaj, after their first absence, Miss Proskouriakoff and Smith learned that Tejeda had uncovered an altar below which was a burial of eleven skulls. He also had uncovered a paved ramp leading downward beneath the frontal platform of the mound. At this point Tejeda left Nebaj to resume his studies at the University of Mexico. He was replaced by Mr. Douglas Binney. Further excavations disclosed that the ramp descended to the entrance of a long passageway leading into a corbel-vaulted tomb similar to the one found in the opposite mound in 1946. Unfortunately, the vault had collapsed, and it was necessary to dig down from the top of the frontal platform in order to get into the tomb. This required digging a pit 8 m. wide and 12 m. deep. The tomb, the earliest found, had been placed in sterile ground well below the foundation of the earliest structure.

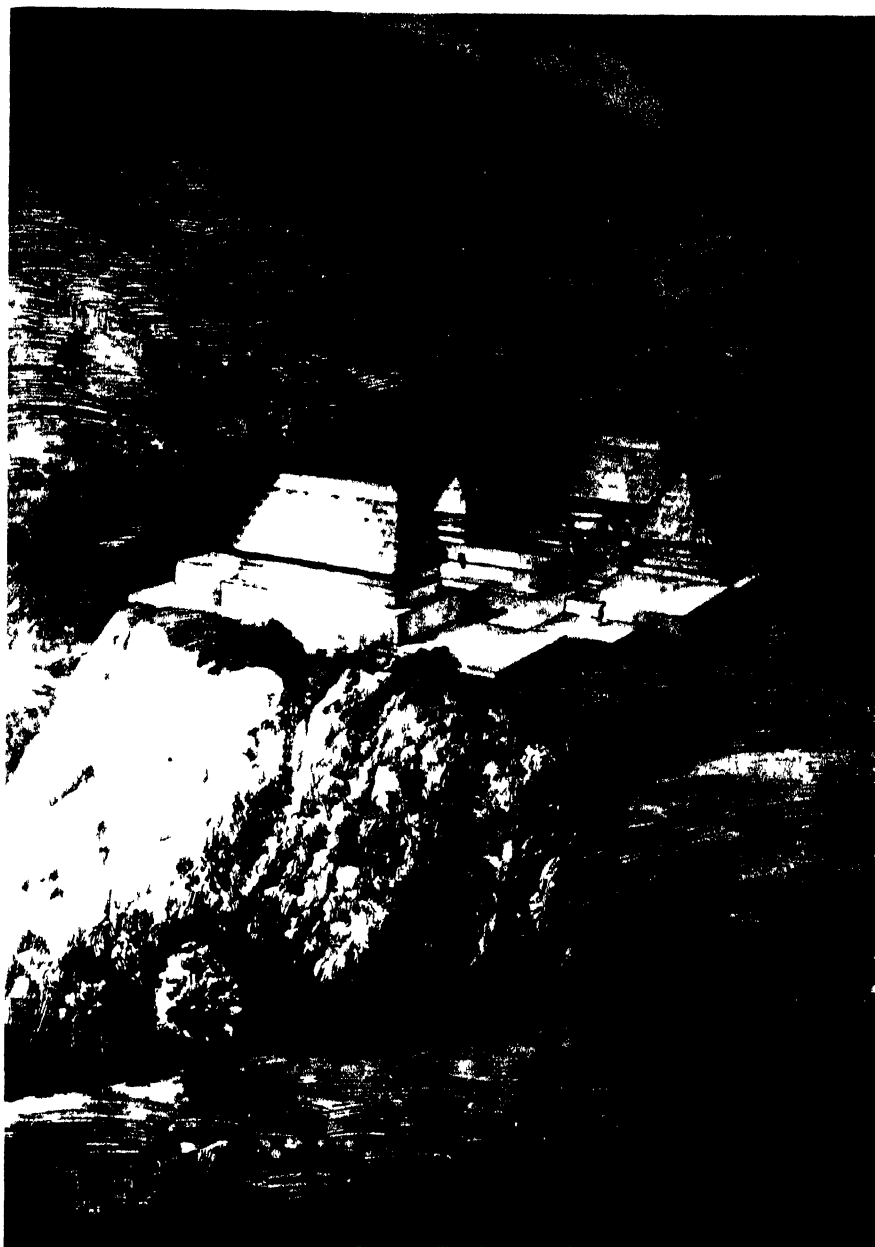
During the excavation required to get into this tomb, a series of eight tombs and twenty-one caches was found associated with six superimposed stairways belonging to a sequence of platforms, several of which were painted red. Fortunately the tombs and caches were so stratified that their relative positions in time could be established. They cover a span of some 700 years of occupation, from the Early Classic period through the post-Classic period of plumbate pottery. The tombs vary in construction. In Early Classic times large chambers were constructed and roofed with corbeled vaults, whereas smaller and narrower tombs were closed with large stone slabs extending from wall to wall. In Late Classic times the large vaulted tombs were abandoned and only long, narrow chambers roofed with large

slabs were used. Still later, in post-Classic (plumbate) times, tombs were roofed with wooden beams supporting stone slabs. In all periods multiple burials were the custom.

Furniture from the tombs and objects found in caches vary according to the style of the period with which they were associated. Such material consists of pottery, alabaster and marble vessels, pottery whistle figurines, beautiful jades in the form of beads and carved pendants and plaques (see pl. 2), shell ornaments, crystal pendants, pyrite mirrors, flint laurel-leaf blades, copper and gold ornaments, incense burners, and the remains of a codex, part of one page of which depicts a priest or ruler in costume. It is interesting to note that at Nebaj outside influence seems to be from the Maya of the Rio Usumacinta area rather than from the Mexicans.

Unfortunately very little architecture was found. The outer structures had been ruined by agriculture, and the inner structures had been cut through or partially removed to put in late tombs. Throughout the work architectural features that came to light and the positions of tombs and caches were recorded on plans and sections by Miss Proskouriakoff. In May she and Binney had to leave, the former to return to the United States. At this time Mr. Gustav Strömsvik joined Smith and assisted him in the completion of the excavations.

During the operations at Nebaj two new sites were visited, Caquixay and Tuchoc. Caquixay is about a two-hour horseback ride east of Cotzal. It is a well preserved site of the Huil type, namely, a ball court and adjoining plaza with an altar platform in the center of the latter. The ball court is of the open-end variety and had the stucco remains of what appeared to be a human head with feathered head-dress in the center of either playing wall.



Tziquay, one of the sites on the Finca San Francisco, Department of Quiche, Guatemala
Reconstruction drawing by T Proskouriakoff



Jade breast ornament from Nebaj. A 5½-inch plaque, dating from about the ninth century, depicting a priest or ruler. The finest piece of Maya jade carving that has yet come to light.

Tuchoc, about halfway between Caquixay and Cotzal, is a site of the same type. Other new sites were located through the kindness of Colonel Arthur Binney, United States Naval Attaché in Guatemala, who took Smith on several flights over the San Andres Sajcabaja area. This area, which lies about 27 km. northeast of Quiche, consists of a large open plain about 1200 m. above sea level. As a result of the survey six sites, which from the air appear to be in a good state of preservation, were located on the plain.

Owing to the length of time taken in the excavations at Nebaj, several investigations had to be postponed until some future date. Among these are a ground reconnaissance of the Sajcabaja area, the mapping of the fortified site at Xolpacol, and an attempt to find at either Chutix Tioa or Xolpacol an undisturbed late tomb of the type which was noted this season but of which both examples had been robbed. The discovery of such a tomb at one of these conquest-period sites would be of the greatest importance, as it should contain objects in use shortly before or at the time of the conquest.

YUCATAN, GUATEMALA, HONDURAS

S. G. MORLEY

On November 11, 1946, Dr. Morley reached Mexico City, where he remained for a week, most of the time in conference with the Hon. Adrian Recinos, former Ambassador of Guatemala to the United States, who translated his recent book *The ancient Maya*, into Spanish, and also with the staff of El Fondo de Cultura Economica, the publishers of the Spanish edition, which appeared in the late spring.

During the winter Dr. Morley was in Yucatan. In April he went to Guatemala, where he visited the ruins of Quirigua, which, thanks to the care given them by

the United Fruit Company, he found to be in better condition—better bushed, kept in better trim, and the monuments better marked with descriptive signboards—than ever before.

Some fear has been expressed that the surface of the sandstone monuments at Quirigua has been deteriorating because of exposure to the sun during the past thirty-six years. The high forest in which they were formerly buried in deepest shade was felled in 1911 by the School of American Research, to remove the danger of falling trees' breaking the monuments, which had occurred in several cases previous to that time. A decade ago, Dr. Morley sprayed Stela K with an English preparation intended to protect sandstone buildings from deterioration, by sealing in the surface of the stone, thus preventing or retarding erosion. His examination of the Quirigua monuments this spring convinced him that the spray had been most successful.

The local Fruit Company officials were so co-operative as to carry out Dr. Morley's recommendation that the bushed area in the Great Plaza be extended. As cleared of trees many years ago by the School of American Research, only the western half of the Great Plaza had been exposed. This not only reduced the apparent size of the plaza by half, but also failed to disclose its function as an amphitheater, a large three-sided enclosure surrounded by ascending tiers of stone seats. The Great Plaza now appears in its true character.

The new National Museum of Guatemala was not yet completely installed in April, but sufficient progress had been made in displaying the large amount of stone material, especially the Piedras Negras stelae and altars, to indicate that it would be one of the leading archaeological museums of America when finished.

The trip Dr. Morley made to Copan in late March was his fifteenth. He found the ruins in a better state of conservation than ever before, owing to the extensive excavations, repairs, and conditioning operations of the Carnegie Institution during the past twelve years, and to the supervisory care given them by the government of Honduras.

A fragment of a new Initial Series was deciphered. This was discovered by Sr. Raul Pavon Abreu, Director of the Museum of Archaeology, History and Ethnology of Campeche, in the debris of Mound 7 at the western end of the Court of the Hieroglyphic Stairway. The inscription was very unusual in that its corresponding period glyphs faced to the right instead of to the left as is overwhelmingly the case in other inscriptions, and the corresponding coefficients were also on the right sides of their period glyphs instead of on their left sides. The reason for this inversion of the usual order was aesthetic, arising from the desire to have the hieroglyphs of this inscription face the central axis of the building on which they had originally been carved. Although the introducing glyph and the day and month signs are still missing, this whole Initial Series may be read as (9).8.8.16.10 (6 Oc 3 Kayab).

Before returning to Yucatan, Dr. Morley visited Tegucigalpa, where he called on Professor Angel Hernandez, Minister of Public Instruction of Honduras, and congratulated him upon the splendid care the government of Honduras is taking of the ruins of Copan, perhaps the most spectacular archaeological site of the Maya Old Empire. Dr. Morley returned to Yucatan April 19 and to the United States at the end of May 1947.

Owing to the death of Dr. E. L. Hewett last December, the directorship of the School of American Research and the Museum of New Mexico, a joint institution

at Santa Fe, became vacant. The managing boards of these two organizations had tendered this position to Dr. Morley, who has been associated with both organizations for many years. Dr. Bush gave Dr. Morley permission to accept the provisional directorship, to serve without salary so long as he should be connected with the Carnegie Institution of Washington, from which he retires July 1, 1949. With this understanding Dr. Morley accepted the position offered him by Mr. Paul A. F. Walter, president of the managing board of the School of American Research, to take effect as of June 1, 1947, pending final approval at the annual meeting of the joint boards on August 23. It is hoped that an amalgamation of all the scientific organizations in Santa Fe, anthropological as well as historical, may be achieved under plans for reorganization already in course of being carried out.

HIEROGLYPHIC RESEARCH

J. E. S. THOMPSON

During the past year Mr. Thompson has continued work on the introductory volume to his study of Maya hieroglyphic writing. This has entailed many unexpected forays into territories which, at the inception of the study, had been deemed sufficiently known to need no further exploration at this stage of the work, but which, it turned out, had to be probed in order to round out the introductory survey of the subject. Consequently, the first volume is not yet completed, but fuller information on specific problems compensates for the delay. For instance, as our knowledge concerning the subject of the hieroglyphic texts accompanying divinatory almanacs in the Maya codices appeared inadequate even for this initial stage, Mr. Thompson devoted much time to that matter, with the result that he now

feels that he can get the general sense of most of those texts, and can offer specific translations of a number of the constantly recurring glyphs.

The problem of the hieroglyphic writing is not one that can be quickly solved. Progress in the past has been discouragingly slow, but now with each additional year of research, the speed increases slightly. During the past year a number of glyphs have been identified, and one or two additions have been made to the very small list of affixes of known meaning. Work on the illustrative material for the volume continues to be rewarding, and the linguistic side of the work has progressed, largely as a result of the very helpful co-operation of Mr. Ralph L. Roys. A point has now been reached at which the absence of full linguistic material on lowland languages and dialects related to Yucatec is making itself felt. It is not improbable that good dictionaries of such Maya languages as Chol, Tzeltal, and Tzotzil would yield homonyms corresponding to apparent examples of rebus writing in the glyphs, for which homonyms are lacking in Yucatec. The situation is roughly what one might expect were one endeavoring to reconstruct Latin from modern Italian, but without access to full material in Spanish, Portuguese, and French. Members of the Summer Institute of Linguistics, who have much unpublished linguistic material from all lowland Maya groups except Chorti, have proffered their co-operation in this work, a generous offer which should prove most helpful.

One chapter and several appendixes of the introductory volume remain to be written, and, in addition, a very thorough revision will be necessary. The greater part of the glyphs to be used as illustrations have now been drawn, and it is hoped that the illustrative material will be completed by the end of the year.

Mr. Thompson was at Bonampak, Chiapas, in February and made drawings of such glyphs on the frescoes as were then visible. Among the sculptured dates recovered at that site are:

Lintel 4 (9. 8. 9.15.11) or (9.11.2.10.11)
7 Chuen 4 Zotz'
Stela 2 (9.17. 5. 8. 9) 6 Muluc 17 Yaxkin
Stela 2 (9.17.18.15.18) 12 Etz'nab 1 Ceh
Stela 4 9.17.15. 0. 0 5 Ahau 3 Muan

There is also an Initial Series on the murals of Temple 1 which Morley has read as 9.13.0.3.4 7 Kan 12 Zec. The lintels of this same temple have yielded two rather uncertain dates, and there is a badly weathered Initial Series of Katun 17 or 18 on the magnificent Stela 1. It is evident that Bonampak was a center of the hierarchic cult for a long period.

MAYA SCULPTURE

TATIANA PROSKOURIAKOFF

The summer and early fall of 1946 were devoted to the preparation of the text which is to be an exposition of the results of researches in Maya sculpture carried on during several seasons. The study deals chiefly with general trends of development in the lowland Maya area as a whole, and these have been briefly summarized in a previous report. Their more detailed statement brings out certain points in regard to the regional distribution of traits which suggest changes in the degree of contact existing between separated sites of the Maya area at different periods of its history.

For the eighth cycle, the material is very meager, and it is not possible to give a clear description of the prevalent styles or their distribution. Strong similarities between Maya sculpture of this period and certain monuments which have been attributed to other cultures on the periphery of the Maya area may be significant. The carving on the Hunucab mouth of the

Cave of Loltun, the stela at El Baul which bears a disputed early date, the sculptures of Santa Margarita and San Isidro Piedra Parada in the Department of Quetzaltenango, and certain monuments of Kaminaljuyu exhibit traits characteristic of the earliest phase of the Early Classic period. Since the seventh-cycle and early eighth-cycle dates suggested by the inscriptions on some of these monuments fall outside the known range of Maya sculpture, stylistic comparison cannot be used to confirm them, but it may in some degree overcome the reluctance to assign these sculptures to an early horizon.

At the end of the Early Classic period (in the first quarter of the ninth cycle) the Maya style appears as an integrated and distinctive entity wherever sculptures of this period are found. This period is followed by a hiatus, and when sculptural activity is resumed, at about 9.8.0.0.0 or 9.9.0.0.0, sculpture shows marked regional differences. Copan retains many characteristics stemming apparently from early Peten, and its style is closely related to that of the Leyden Plate. The most advanced characteristics seem to appear first in the western half of the area and to the north, indicating that the impetus of the new development came from either of these two directions. As the Late Classic period progresses there is a rapid fusion of regional styles, and particularly a spread eastward of Usumacinta traits. Complexes of traits noted at the beginning of the period at Piedras Negras become common in Copan after 9.14.0.0.0. Another group of traits links the Usumacinta and specifically Yaxchilan with the Puuc area of Yucatan. Although such stylistic similarities do not in themselves demonstrate direct contact between sites, they furnish valuable leads for the study of the relations existing between diverse regions.

In the winter of 1947 the study was in-

terrupted by a field trip to the highlands of Guatemala in connection with the survey of that area reported by A. L. Smith. It was resumed in May, when we were very glad to acquire the services of Miss Kisa Noguchi in the preparation of illustrations which will be the basis of the method of stylistic appraisal proposed in the study.

CERAMIC TECHNOLOGY

ANNA O. SHEPARD

The principal activities during the current year have been preparation of material for a ceramics handbook, study of a punch-card system, and preliminary analysis of Usulután ware. In addition, a section was added to a paper on the symmetry of abstract design, previously considered completed. Early material from the Pueblo region recently published by Dr. J. O. Brew suggested the new section, which is devoted to all-over patterns and a review of evidence of the influence of basketry design on early pottery design.

The purpose of the ceramics handbook is threefold: (1) to present for the archaeologist that part of technical and scientific ceramics which is applicable in our field, (2) to summarize and critically to evaluate methods of archaeological ceramic description and analysis, and (3) to consider the place of ceramic data in archaeology and to examine the basis of our interpretations. There has long been need for an outline of ceramics written expressly to give the archaeologist background for understanding the technical features of pottery, particularly as scientific knowledge of the clay minerals has undergone marked advance in the past twenty years and much pertinent information has appeared only in technical journals. The review of analytical procedures will cover shape and decoration as well as technical features. A

number of methods developed in our own work will be described, and attention will be given to field tests for the archaeologist.

Our ceramic studies have reached the stage at which a comprehensive review has become desirable. Extensive summarizations and comparisons require means of sorting rapidly the accumulated data. The practicability of a punch-card system for hand sorting has been tested in both technical and stylistic work. Immediate application of the system in technological analysis was found in an index of our collection of some 3500 thin sections. A code covering provenience, period, pottery classification, paste composition, and various technical features has been devised, and cards have been printed. Sections of Peten and Copan pottery have been indexed to date, and the advantages of the method have been effectively demonstrated. Punch cards have proved no less applicable in stylistic analyses, particularly of entire and restorable vessels. Revision of method in these studies is desirable because our material is limited in extent and is scattered. To base comparative and distributional reviews on published illustrations is time-consuming and often unsatisfactory. Doubtless the fact that the bulk of archaeological ceramic material is in the form of sherds has directed and restricted our studies more than we ordinarily realize. We have inevitably been led to give undue prominence to secondary features such as color, texture, and wall thickness because they are easily determined in the fragment, which may give only a hint of vessel shape and design. Consequently ceramics as an aspect of material and artistic culture has been neglected for potsherds used as a tag for place and period. Without depreciating the potsherd, one may point to the desirability of bringing together a record of available, significant, entire vessels. A photographic file

such as that started in the Cambridge office of the Division of Historical Research is beginning to be recognized as a requisite for comparative work; but with the ordinary indexing system it soon becomes unwieldy, and locating specimens and returning them to the file is discouragingly time-consuming. Punch cards fully meet this difficulty, since with a sound and comprehensive code a wide variety of classes and of specific traits can be sorted rapidly; moreover, filing is eliminated. Considerable time has therefore been given to the development of systematic classifications of vessel shapes, decorative techniques, and design styles to insure a logically consistent and comprehensive code. A trial set of cards prepared for Usulután ware is being used to test the code. It is hoped that when the system is perfected, other institutions will be sufficiently interested to adopt it and thus initiate a co-operative project for exchange of material. A number of archaeologists, including a large group of Mexican authorities, have been consulted on the code for cultural regions and have shown a splendid spirit of co-operation.

Usulután, the principal type of pottery analyzed during the current year, is one of the more widely distributed wares of the Archaic period and therefore affords opportunity for study of contacts and spread of influence on that horizon. Neither the decoration, which is simple and geometric in a technique long misunderstood, nor vessel form, which is varied and elaborate, has so far shed light on centers of production or on volume and extent of trade. The ware occurs mainly in the region of younger volcanic formations of Guatemala and Salvador; most of it is tempered with volcanic ash. When these conditions obtain, the feasibility of using paste composition to distinguish pottery from different sources may be ques-

tioned, and the Usulután study can therefore be considered a test case. The preliminary microscopic examination of a large collection from Miraflores and smaller samples from Copán, a number of localities in Guatemala, and several in Salvador has been encouraging. Eight distinct varieties of ash associated with different types of clay have so far been noted. Their distribution indicates distinct sources, and it is clear even from the preliminary examination that the ware was made in a number of districts and that there was considerable interchange between them. Relations will be plotted in detail as analysis proceeds. Possible local variation in style will also be studied by correlating form and composition. This evidence bears on the question of broad trends in ceramic history. It has appeared that the pottery of the Archaic period exhibits less regional specialization than that of the Classic, a possible difference which suggests a general parallelism with Pueblo ceramic development. But individual styles are less conspicuous among the predominant monochromes of the Archaic than among the polychromes of the Classic, and the fundamental obstacle in testing this generalization has been uncertainty as to amount of exchange and inability to distinguish indigenous from imported pottery by appearance alone, except in the case of a few striking types. There is now assurance that composition will afford a reliable basis for investigating the problem of local specialization in this area as it has in others.

EARLY CULTURES OF SOUTHWESTERN UNITED STATES

EARL H. MORRIS

Early in the year 1946-1947, Mr. Morris completed the study of a group of Basket Maker ceremonial sashes from north-

eastern Arizona. These textiles were found in a cave which yielded timber dates ranging from A.D. 473 to 478. Despite their age, the sashes were in a perfect state of preservation, and it was possible to recover every detail of the technique employed in their manufacture. The material was dog hair, hand-spun into slender threads which were flat-braided into long, narrow bands adorned with bead-strung tassels and fringes at the ends. The largest is 3 m. long by 6 cm. wide, composed of 119 individual strands. Analysis of these sashes throws additional light on the virtuosity of the early aborigines of the Southwest in the art of weaving.

Some two months were spent in recording and photographing a collection of specimens from a cave near Durango, Colorado. This collection, property of the Mesa Verde National Park Museum, contains the only perishable materials of Basket Maker age that have been found in the region. Results of the study will be incorporated in a report on excavations in the vicinity of Durango conducted by Carnegie Institution in 1939 and 1940.

The remainder of the year was devoted to a detailed analysis of Anasazi cloth sandals from the Four Corners region of the Southwest. The Anasazi developed sandal-making into a fine art which continued to be practiced for a full millennium, roughly from early in the second century of the Christian era to about 1250. Upon the manufacture of their footgear they lavished their utmost in mechanical skill and artistic ability. Certain of the sandals exemplify some of the most complex finger weaving that the world has ever seen. Richness of ornamentation is equally extensive and intricate. It is of two kinds: colored, attained by the introduction of dyed weft threads; and structural, produced by devious manipulations of the weft strands in the uncolored areas.

Of no other early American art in perishable media have so many examples survived. Hence it is felt that a complete record of the life history of this art is both justifiable and important. Work toward this end, which was halted by the war, was resumed by the artist-draftsmen assisting Mr. Morris, as soon as they were released from service. It is expected that this work will continue without further interruption until complete data have been obtained and put in form for publication.

LINGUISTIC RESEARCH

NORMAN A. MCQUOWN

Mr. McQuown undertook the continuation of the work on the Maya Linguistic Project on September 1, 1946. He devoted the first month to familiarizing himself with and making an inventory of the Maya materials collected by the late Dr. Manuel J. Andrade and elaborated by Abraham M. Halpern during the relatively brief period which he was able to devote to this task (see Year Book No. 40, pp. 308-309; No. 41, pp. 274-275). A program of work for the year 1947 was sketched out. In this, Mr. McQuown was guided by the interim report on the state of the project prepared by Mr. Halpern in July 1946, before he left for duty with General MacArthur in Japan. The more important parts of this report are outlined here:

- A. The basic aims of the work on the Maya languages:
 1. The glaring deficiencies in the amount and quality of available *primary source material* should be corrected.
 2. A certain amount of the material collected should be synthesized in the form of *grammatical sketches*.
 3. The material should be examined from the point of view of *comparative linguistics*, so that ultimately the general lines of development of the Maya language family could be laid down.
 4. In the course of the achievement of the first three objectives, *special problems* of particular interest, either for general linguistics or for workers in the related fields of Maya archaeology and ethnology, would at least be indicated, if not worked out exhaustively.
- B. The general goal of the Maya linguistic research: The research was designed not so much to produce the last word on all problems of Maya linguistics as to complete basic research and arrive at basic conclusions of a sort that would put Maya linguistic research on its feet scientifically.
- C. Necessity of the work: That this research was necessary is beyond all possibility of question. The available materials of a descriptive nature were thoroughly antiquated. In the field of comparative Maya linguistics, deficiencies in the descriptive data made it impossible to arrive at conclusions based on anything more than the most superficial kind of inspection.
- D. Status of the project at present: Of the objectives mentioned above (A), Andrade went a long way toward realizing the first, the compilation of material. With regard to the second objective, he had, before his death, almost arrived at the completion of a grammar of Yucatecan Maya, but had put nothing on paper with regard to the other languages. For all the languages except Yucatec, the material is in the form of raw field data. With regard to the third objective, Andrade accomplished little or nothing. With regard to the fourth, he called attention to the possibilities inherent in the application of dialect-geography techniques to at least the Guatemalan languages and had begun to collect materials on which such a study could be based, but he had not initiated the work of processing the materials toward this end.
- E. Materials collected by Andrade:
 1. *Huastec*: a rather extensive body of text materials, vocabulary and paradigmatic material for the Potosino dialect, and a relatively small body of material of the Veracruz dialect.

2. Yucatan-Guatemala languages: an extensive amount of material on *Yucatec*, *Mam*, and the Panajachel dialect of *Cakchiquel*; a moderately extensive amount of material on *Quiche* and *Quekchi*; small bodies of material on *Pokomam*, various *Tzotuhil* and *Cakchiquel* dialects, *Aguacatec*, and *Jaltec*.

3. Chiapas languages: very small amounts of material.

F. Condition of the materials: Linguistic materials in the form of raw field notes are rarely susceptible to immediate exploitation by anyone other than the original collector. The process of collection of field material is such that every investigator is forced to adopt certain expedients which depart in one way or another from standardized practice, and an investigator rarely leaves a complete record of such departures and the reasons for them. With Andrade's death, a great deal that he knew but had not written down was lost irrevocably.

There are certain inconsistencies in recording. In many cases one cannot be sure which of two or three variant recordings represents the norm for any given word and which are variations from the norm. In some cases, one can decide on the basis of the notes that the balance of likelihood is in favor of one variation rather than another. An unsolved phonetic question of major importance in all the languages is the presence or absence of phonemic length and accent. In most cases of variant recordings, different interpretations are possible, but if one operates entirely from Andrade's field notes, it is difficult, perhaps impossible, to decide which interpretation best fits the facts.

These difficulties exist if one relies exclusively on the field notes as they stand or on the phonograph records, which unfortunately fail one on many of these points. A short period of field work, in which an investigator would have the opportunity of observing the phonetics at first hand, would, however, be sufficient

to settle all the doubtful points and would even enable the investigator to make use of untranscribed phonograph records.

It is now customary among linguistic field workers to supplement text material by extensive collections of paradigmatic material relevant to the analysis of the texts. Andrade's technique was somewhat different from this. His questions were standardized for all languages in order to facilitate comparison on certain specific points of grammatical structure. This material is extremely useful, but needs some supplementation.

G. Recommendations for further work of compilation:

1. The investigator should have the opportunity to familiarize himself with the *phonetics* of the various languages through direct field work.
2. The investigator should have the opportunity to collect further *paradigmatic material*.
3. The investigator should devote some time to the collection of *folkloristic texts* where obtainable.

H. Recommendations for further descriptive and comparative work:

1. The *Yucatec grammar* is already well handled, so little or no further work need be done there.
2. A *grammar of the Potosino dialect of Huastec* should be an immediate task.
3. Concentration on *Mam* in the Yucatan-Guatemala area is recommended, since the *Mam* materials are among the most extensive in the collection, and one can expect to find certain archaic features preserved in *Mam* which have been lost in some of the other languages.
4. If time permits, one of the *Chiapas* languages should be investigated intensively and the others merely surveyed.
5. The *dialect study* of the *Cakchiquel* and *Tzotuhil* area should be carried out, but should be treated as a pilot study in which the objective would be

to formulate the types of problems that arise and to indicate the methods which are applicable.

6. The elucidation of the *internal relationships* within the Maya family and the *reconstruction* of Primitive Maya should be prime objectives.
7. It is very probable that in the course of reconstructing Primitive Maya, the scholar engaged on this task will find leads indicating the direction in which *external relationships* must be sought.

Mr. McQuown accordingly devoted the following two months to getting acquainted with Andrade's phonetically and phonographically recorded Potosino Huastec materials, and with the dictionary materials compiled by Halpern from the raw data. It soon became apparent that a small number of fairly important phonological problems and a large number of morphological questions could not be solved on the basis of the available material. Accordingly, a field trip to Las Armas, San Luis Potosi, Mexico, was undertaken; nine days were devoted to the collection of a vocabulary of about 2000 items, a considerable amount of paradigmatic material related to the verb, and a couple of texts. With this material, together with general notions obtained from the survey of the previously collected material, it was possible to work out the sound system and a beginning was made toward working out the morphology and syntax. The elaboration of the materials gathered on this field trip was continued during the first six months of 1947, when the major portion of Mr. McQuown's time was devoted to teaching linguistics in the Department of Anthropology at the University of Chicago. A start was made on the compilation of a Spanish-keyed comparative Maya vocabulary, from which will be drawn the cognate material to be used in working out the sound-correspondence matrix for the

various languages of the family, and for reconstructing Proto-Maya.

Mr. S. L. Bradshaw, commissioned by the Institution to prepare the manuscript of Andrade's Yucatec grammar for the printer, completed his work and submitted the manuscript early in 1947.

It is hoped that by 1950, the general outlines of a comparative Maya grammar may be laid down.

ANTHROPOMEIRY OF THE HIGHLAND MAYA

T. D. STEWART

The late Dr. Aleš Hrdlička had planned to visit Guatemala in December 1943 to take measurements and observations on the highland Maya, but he died in September of that year. His successor in the curatorship of the Division of Physical Anthropology, United States National Museum, Dr. T. D. Stewart, finally undertook this work during the first three months of 1947. His trip was made in co-operation with the Guatemalan government and under the program for co-operation with the American republics through the State Department and the Smithsonian Institution. In addition to studying the living, Dr. Stewart examined the available prehistoric skeletal remains, especially those recovered at San Agustín Acasagustán (A. L. Smith and A. V. Kidder, *Explorations in the Motagua Valley, Guatemala*, Carnegie Inst. Wash. Pub. 546, 1943), at Kaminaljuyu, and at Zaculeu.

The main objective of Dr. Stewart's trip was to obtain information about the highland Maya which would enable him to make comparisons with the lowland Maya of Yucatán. These two groups, although rather widely separated geographically and exhibiting differences in material culture, nevertheless belong to the same linguistic stock. According to J. Alden Mason (*The Maya and their neighbors*, 1940, p. 70),

"The Mayan stock is unusually homogeneous both as regards geographical location and linguistic differentiation. It is really too unified for even the major divisions to deserve the rating of 'families,' and many of the so-called 'languages' differ only dialectically." Since language is fairly resistant to change (more so than material culture), considerable interest attaches to the question whether this linguistic homogeneity reflects a similar status in physical type.

Anthropometric records on the Maya Indians of Yucatan, obtained through the interest of the Carnegie Institution by G. D. Williams and Morris Steggerda, have already been published (*Maya-Spanish crosses in Yucatan*, Papers Peabody Museum, Harvard Univ., vol. 13, 1931; *Anthropometry of adult Maya Indians*, Carnegie Inst. Wash. Pub. 434, 1932; *Maya Indians of Yucatan*, Carnegie Inst. Wash. Pub. 531, 1941). For the highland groups of Guatemala, on the other hand, only two anthropometric studies are on record, one by Oliver La Farge and Douglas Byers (*The Year Bearer's people*, Tulane Univ. Middle Amer. Research Ser., Pub. 3, 1931) and the other by Ada d'Aloja (*Sobre la variabilidad de algunos caracteres antropométricos observados en grupos de Indígenas Centroamericanos*, Inst. Panamericano de Geogr. e Hist., Pub. 43, 1939). Neither of these Guatemalan studies, which are themselves not very well known, includes comparisons with Yucatan.

Dr. Stewart undertook the collection of data that would supplement those already available and at the same time allow their fuller interpretation. Since in Guatemala the municipio, being endogamous, is the basic unit for ethnic study, as Dr. Sol Tax has shown (*The municipios of the mid-western highlands of Guatemala*, Amer. Anthropologist, vol. 39, 1937), Dr. Stewart restricted his study to two municipios

within one linguistic subgroup, the Cakchiquel. First at Solola, Department of Solola, and later at Patzun, Department of Chimaltenango, he obtained comparable series of males, 82 and 72 respectively. At Patzun, moreover, he obtained a series of 35 females. All together this is the largest series from one highland linguistic group thus far studied.

In addition to the routine anthropometric measurements, observations, and photographs, the records obtained this season include blood groups (A, B; M, N), taste sensitivity to phenyl-thiocarbamide, palm- and fingerprints, and hair samples. Arrangements have been made for Dr. William C. Boyd, of Boston University School of Medicine, to analyze the blood groups and taste records, and for Dr. Harold Cummins, of Tulane University Medical School, to analyze the dermatoglyphics.

Preliminary inspection of the anthropometric records indicates that the Cakchiquel are lighter-complexioned, slightly lighter in weight, longer-headed, narrower-faced, and broader-nosed than the lowland Maya of Yucatan. Also, there are some significant metrical differences between the samples from Solola and Patzun, a fact which suggests that, as suspected, inbreeding is producing local varieties in the highlands.

In his examination of the skeletal remains Dr. Stewart gave special attention to evidences of cultural practices, such as artificial deformation of the head and dental mutilation. The former, almost universal in the collections examined, mostly consisted in flattening of the occiput in the vertical plane ("cradleboard deformity") combined with frontal flattening. Previously this type had been reported only from Tajumulco (*Skeletal remains from Tajumulco, Guatemala*, Monogr. School Amer. Research, 1943). In other cases, es-

pecially at Kaminaljuyu, only frontal flattening was present. Also, at Zaculeu some evidence of the so-called "lambdoid" deformity was found in skulls from the most recent tombs.

As for dental mutilations, five examples of filed teeth were observed in the Zaculeu collections. One of these is a new type, or at least not included in the Borbolla key (*Types of tooth mutilation in Mexico*, Amer. Jour. Phys. Anthropol., vol. 26, 1940), whereas the others are types known from elsewhere in the Maya area.

It is regarded as desirable that the experience gained in this successful first season be utilized for the extension of these observations elsewhere. For example, it is important to learn to what extent in the highlands the barrier of language is an aid in the formation of physical types. In this connection the Quiche, neighbors of the Cakchiquel, or the Mam, neighbors in turn of the Quiche, should be more fully studied. If the records are made by one observer, moreover, they will be more uniform and less subject to multiple personal biases.

HISTORY OF THE MAYA AREA

RALPH L. ROYS

During the past year the comparative study of the Books of Chilam Balam has been continued. Especial attention has been given to the Codex Pérez, and a guide to this manuscript has been prepared to accompany the reproduction in the Peabody Museum of Harvard University.

The Codex Pérez consists of extracts which J. Pío Pérez copied from various Maya manuscripts, apparently during the second quarter of the nineteenth century. A large part of it was taken from the lost Book of Chilam Balam of Mani. There have been transcriptions, but only in recent years was Dr. S. G. Morley able to obtain

a photograph of the original for the Carnegie Institution of Washington.

The first third of the manuscript is composed largely of Maya translations of European astrological and calendrical material (Year Book No. 45, pp. 220-221), which appealed to the interests of the more Hispanicized element of the Indian population; but most of the remainder is devoted to the native lore. The Codex Pérez covers a wide range of Maya learning and pays much attention to the augural or divinatory aspects of the Maya calendar. Here are predictions of the coming of the Spaniards and the new religion, prophecies for the tuns or years, and others for the 20-year periods called katuns with their valuable historical allusions. Of especial interest are the famous Mani Chronicle, several isolated historical narratives, and a version of the creation story differing in some respects from any that has been published. As in other Books of Chilam Balam, we find indications of the close association between history and prophecy in the Maya mind. One passage presents an important aspect of native Maya astrology, and there are several long explanations of Maya chronology. In spite of some chronological errors, these disquisitions add considerably to our knowledge of the native terminology and the point of view of the Indians who were endeavoring to preserve the old traditions. Besides the material not found elsewhere, there are parallels of passages in other Books of Chilam Balam; but in general the Codex Pérez versions are fuller and furnish more details.

In a previous report (Year Book No. 44, pp. 181-183) attention was called to chronological concepts expressed in certain prophecies in the Books of Chilam Balam of Tizimin and Mani. For the better understanding of this aspect of Maya science, a tentative translation has been made of a series of prophecies for the 20

tuns of a Katun 5 Ahau alleged to begin in 1593. In its present form the series is the work of eighteenth-century compilers, and the chronological setting is incorrect; but the greater part of the content appears to have been copied from earlier manuscripts. Although it seems plain that the prophecies really apply to the tuns, more emphasis is placed on the year-bearers. It is true that pessimism predominates in other Maya prophecies, but here the news is almost invariably bad. The language is often symbolic. Mythological allusions are frequent, but only rarely are they to the better-known and more important deities. A number of the names, such as Chac-uayab-xoc ("great demon shark"?) and Chac-mumul-ain ("great muddy crocodile"?), suggest fabulous monsters. Fauna names are sometimes preceded by a numerical coefficient, such as Ah Uucte-cuy ("7-owl") and Ah Uuc-ch'apat ("7-centipede"). These may be mythological personages, but the close association of the name Ah Buluc-am ("7-spider") with Montezuma suggests that it was considered to be the Maya name of the latter.

During this period work has been done on collecting and cataloguing material from sixteenth-century sources for a study of the political geography of the Yucatan peninsula at the time of the Spanish conquest, a joint project of Dr. Scholes and Mr. Roys. Time has also been devoted to reading proof of the history of the Chontal Indians of Acalan-Tixchel.

HISTORY OF THE MAYA AREA

FRANCE V. SCHOLES AND ELEANOR B. ADAMS

Work has been done on collecting and cataloguing material from sixteenth-century sources for a study of the population and political geography of the Yucatan peninsula, a joint project of Mr. Scholes and Mr. Roys. This work has included the

study of data previously assembled and the investigation of additional documentary series, chiefly encomienda papers and proofs of services of conquerors, soldiers, and early settlers of Yucatan. The collection of the data is now nearing completion, and during the coming months the final study should begin to take form.

Miss Adams has carried forward her investigations of the foreign corsairs who scourged the coasts of Yucatan in the sixteenth century. The spadework research for this study, which has necessarily included the study of a wide range of supplementary sources in addition to those directly relating to events in Yucatan, is now virtually complete. Miss Adams will spend a considerable part of the coming year in writing up the data as a separate monograph.

These two studies will help to lay the foundation for the general history of Yucatan in the sixteenth century, the major project of Mr. Scholes at present. For this larger work some documentary research remains to be done, but the major series of documents have been rather thoroughly surveyed or extracted. The general plan of the history has also been worked out in some detail, and outlines have been made for several chapters.

Finally, considerable time has been devoted to the reading of proof of the history of the Chontal Indians of Acalan-Tixchel, now in press.

HISTORY OF THE MAYA AREA

ROBERT S. CHAMBERLAIN

Mr. Chamberlain's work has consisted of an investigation of the Spanish conquest period, roughly 1517-1550, in Yucatan, Tabasco, Honduras, Chiapas, and adjacent territories. His writing is based primarily on extensive research in documents existing in the Archivo General de Indias de

Sevilla, the Archivo Histórico Nacional, Madrid, the Archivo General del Gobierno, Guatemala City, and to a lesser degree in the Biblioteca Nacional, Madrid, the Archivo General de Simancas (Spain), and the Archivo General de la Nación, Mexico City. This research has helped to close important gaps in the history of the former Spanish provinces named above, to correct earlier accounts, and to re-evaluate, or evaluate for the first time, the course of events.

Mr. Chamberlain's research has made possible the preparation of two major works, one on the conquest and colonization of Yucatan, and the other on the conquest and colonization of Honduras, for publication by the Carnegie Institution of Washington, and brief monographs and articles for publication by the Carnegie Institution of Washington and by various historical journals. Because of the interlocking nature of much of the documentary source material, the preparation of the manuscripts of the two major studies was carried on concurrently, the manuscripts being completed some months apart.

The principal new contributions to Spanish colonial history resulting from Mr. Chamberlain's work have been:

1. The history of the conquest of Yucatan has been corrected, amplified, and re-interpreted.

2. The history of the conquest of Honduras has been fully told. Five unknown years, 1539-1544, important for the governmental evolution of Honduras and for the extension of the conquest, have been added to the history of the province. The conquest of Higueras, the western and, in the colonial period, the most important part of Honduras, has been more fully told, and new interpretation has been given to the early history of the province as a whole.

3. Four years have been added to the

history of Chiapas, 1540-1544, when Francisco de Montejo, who was also Adelantado of Yucatan and Governor of Honduras, was governor of that province. This has been done in a brief monograph which is being published as Contribution 46 in the Contributions to American Anthropology and History (Publication 574).

4. Through the histories of the conquest and colonization of Yucatan and Honduras, Francisco de Montejo has been revealed as one of the truly great Spanish conquistadors and administrators. Montejo's career has hitherto been neglected. He was a man of great stature and vision, an empire builder in the real sense. Mr. Chamberlain is drawing up an outline on which to base a biography, as such, of Montejo.

In addition, on the basis of documents from the Archivo General del Gobierno, Guatemala City, it has been possible for the first time to give an account, even though a very brief one, of the early history of the town and province of San Miguel, now the southern part of the Republic of El Salvador.

During the period which Mr. Chamberlain has had under study, fusion of European culture, as represented by the Spaniards, with native New World cultures, and mixture of European and Indian races not only began but progressed rapidly. Spanish governmental, religious, economic, and social forms, institutions, and attitudes were speedily imposed on the Indians. At the same time the Indians sought tenaciously to cling to their own cultures. It is this continuous and fundamental clash and fusion of European and native American cultures and races which have given most of the Spanish American countries their past, present, and future form and aspect. It scarcely need be pointed out that greater knowledge of the past and present of the countries and peoples of

Latin America is becoming increasingly important in view of the fact that the United States is now forging more closely than ever before its political, economic, military, and cultural bonds with the other nations of the western hemisphere.

HISTORY OF SCIENCE

GEORGE SARTON

Introduction to the history of science. Most of Dr. Sarton's time was devoted to proofreading of volume III. At present the page proofs of the whole work have been read (xxxv+1910 pages), but the compilation, editing, and printing of the indexes remain to be done. It is hoped that the whole work may be published before the end of 1947.

Editing of Isis. Publication of *Isis* by the Harvard University Press was slowed up in 1946 but is now improving. During this year there were published nos. 85, 105-108 of *Isis*, forming the first halves of volumes 32 and 37 and the second half of volume 36. These five numbers comprise a total of 501 pages, with 8 plates and 35 figures, and include 33 main studies, 70 notes, 99 reviews, and about 1000 bibliographic items.

Lecturing in Harvard University. Two courses were delivered this year, dealing respectively with the history of science from the sixteenth to the seventeenth century, and with the history of modern science, the number of students being 212 and 350. Efforts are being made to reduce the size of these audiences.

Ancient science down to Epicurus. Work on this project had to be stopped until volume III is finished.

PUBLICATIONS

MARGARET W. HARRISON

The long-delayed *Album of Maya architecture* (Publication 558), by Tatiana

Proskouriakoff, was distributed in December 1946.

The Maya Chontal Indians of Acalan-Tixchel: a contribution to the history and ethnography of the Yucatan Peninsula (Publication 560), under the joint authorship of France V. Scholes and Ralph L. Roys, is completely in galley proof, and the gravure facsimiles of the Chontal Text are made. It is expected that this book, the second in a series of historical studies, will go to final press before the end of 1947. The manuscript of a third volume in this group, Robert S. Chamberlain's *The conquest and colonization of Yucatan, 1517-1550*, has been prepared for the printer and will shortly be presented for publication. Dr. Chamberlain's next manuscript, *The conquest of Honduras and Higueras*, is now being edited.

Excavations at Kaminaljuyu, Guatemala (Publication 561), by A. V. Kidder, J. D. Jennings, and E. M. Shook, with technological notes by Anna O. Shepard, was printed early in 1947, but lack of binding facilities has delayed its distribution. Delivery is expected in July. In addition to over 300 pages of text, the book contains 207 figures, about half of them gravure, of which four are in color.

Anna O. Shepard's *Plumbate: a Mesoamerican trade ware* (Publication 573) awaits paging. Much of the text is arranged to face the specific illustration being discussed. Of its 44 figures, about two-thirds are gravure.

Volume IX of *Contributions to American Anthropology and History* (Publication 574), now in galley proof, contains four papers: *An archaeological reconnaissance in the Cotzumalhuapa region, Escuintla, Guatemala* (no. 44), by J. Eric S. Thompson; *Textiles of pre-Columbian Chihuahua* (no. 45), by Lila M. O'Neale, professor of decorative art in the University of California, Berkeley, to which is ap-

pended a chemical analysis of the coloring matter by Michael Kasha, of the university's Department of Chemistry; *The governorship of the Adelantado Francisco de Montejo in Chiapas, 1539-44* (no. 46), by Robert S. Chamberlain; and *The symmetry of abstract design, with specific reference to ceramic decoration* (no. 47), by Anna O. Shepard.

The artifacts of Uaxactun, Guatemala (Publication 576), a 76-page monograph by A. V. Kidder, has been released for final printing. It forms part of the general survey of work at Uaxactun, reports on the architecture and ceramics to be written by A. L. and R. E. Smith, respectively.

Early in 1947 the Division issued a small *Guide book to the ruins of Copan* (Publication 577), by Gustav Strömsvik, with maps of the site and halftone illustrations of outstanding features. A brief mention of books recommended for a general background of Maya culture is appended.

To the third volume of Notes on Middle American Archaeology and Ethnology fifteen numbers were added during the year. Six papers from members of the staff, Miss Proskouriakoff and Messrs. Kidder, Roys, Shook, Strömsvik, and Thompson, are listed in the bibliography at the end of this report. Authors outside the Institution contributed the remainder: *Some Mexican figurines of the colonial period* (no. 70), *The codex of the Derrumbe del Templo Mayor* (no. 72), *Some examples of Yeztla-Naranjo geometric ware* (no.

73), *The "Tortuga" of Coatlan del Rio, Morelos* (no. 76), and *Stone objects from Cocula and Chilacachapa, Guerrero* (no. 80), by R. H. Barlow; *Otomi looms and quechquemilts from San Pablo, State of Puebla, and from Santa Ana Hueytlalpan, State of Hidalgo, Mexico* (no. 78), by Bodil Christensen; *Easter ceremonies at San Antonio Palopo, Guatemala* (no. 81), by Elsie McDougall; *The treble scroll symbol in the Teotihuacan and Zapotec cultures* (no. 74), by Horace Neys and Hasso von Winning; and *Drawings of Tajumulco sculptures* (no. 77), by Antonio Tejeda. The last constitutes an illustrated supplement to *Excavations at Tajumulco, Guatemala* (Monograph 9 of the School of American Research), by Bertha P. Dutton and Hulda R. Hobbs.

John M. Longyear III wrote *Cultures and peoples of the southeastern Maya frontier* as no. 3 in Theoretical Approaches to Problems, a series published by the Division to offer a forum in which tentative solutions and hypotheses are presented to stimulate interest in the final synthesis of Middle American cultural history.

In addition to seeing these publications through the press, Mrs. Harrison is engaged in editing the manuscript of *The Maya chronicles*, by Alfredo Barrera Vasquez and Sylvanus G. Morley. Work on her dictionary of archaeological terms is temporarily halted pending revision of ceramic nomenclature.

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1948 1949

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813 Santa Barbara Street, Pasadena 4, California

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ORGANIZATION, PLAN, AND SCOPE

The Carnegie Institution of Washington was founded by Andrew Carnegie, January 28, 1902, when he gave to a board of trustees an endowment of registered bonds of the par value of ten million dollars. To this fund an addition of two million dollars was made by Mr. Carnegie on December 10, 1907, and a further addition of ten million dollars was made by him on January 19, 1911. Furthermore, the income of a reserve fund of about three million dollars, accumulated in accordance with the founder's specifications in 1911, is now available for general use, and in recent years a total of ten million dollars has been paid by the Carnegie Corporation of New York as increase to the Endowment Fund of the Institution. The Institution was originally organized under the laws of the District of Columbia and incorporated as the *Carnegie Institution*, articles of incorporation having been executed on January 4, 1902. The Institution was reincorporated, however, by an act of the Congress of the United States, approved April 28, 1904, under the title of the *Carnegie Institution of Washington*. (See existing Articles of Incorporation on following pages.)

Organization under the new Articles of Incorporation was effected May 18, 1904, and the Institution was placed under the control of a board of twenty-four trustees, all of whom had been members of the original corporation. The trustees meet annually in December to consider the affairs of the Institution in general, the progress of work already undertaken, and the initiation of new projects, and to make the necessary appropriations for the ensuing year. During the intervals between the meetings of the trustees the affairs of the Institution are conducted by an Executive Committee chosen by and from the Board of Trustees and acting through the President of the Institution as chief executive officer.

The Articles of Incorporation of the Institution declare in general "that the objects of the corporation shall be to encourage, in the broadest and most liberal manner, investigation, research, and discovery, and the application of knowledge to the improvement of mankind."

The Institution is essentially an operating organization. It attempts to advance fundamental research in fields not normally covered by the activities of other agencies, and to concentrate its attention upon specific problems, with the idea of shifting attack from time to time to meet the more pressing needs of research as they develop with increase of knowledge. Some of these problems require the collaboration of several investigators, special equipment, and continuous effort. Many close relations exist among activities of the Institution, and a type of organization representing investigations in astronomy, in terrestrial sciences, in biological sciences, and in historical research has been effected. Conference groups on various subjects have played a part in bringing new vision and new methods to bear upon many problems. Constant efforts are made to facilitate interpretation and application of results of research activities of the Institution, and an Office of Publications and Public Relations provides means for appropriate publication.

ARTICLES OF INCORPORATION

PUBLIC No. 260. An Act to incorporate the Carnegie Institution of Washington.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the persons following, being persons who are now trustees of the Carnegie Institution, namely, Alexander Agassiz, John S. Billings, John L. Cadwalader, Cleveland H. Dodge, William N. Frew, Lyman J. Gage, Daniel C. Gilman, John Hay, Henry L. Higginson, William Wirt Howe, Charles L. Hutchinson, Samuel P. Langley, William Lindsay, Seth Low, Wayne MacVeagh, Darius O. Mills, S. Weir Mitchell, William W. Morrow, Ethan A. Hitchcock, Elihu Root, John C. Spooner, Andrew D. White, Charles D. Walcott, Carroll D. Wright, their associates and successors, duly chosen, are hereby incorporated and declared to be a body corporate by the name of the Carnegie Institution of Washington and by that name shall be known and have perpetual succession, with the powers, limitations, and restrictions herein contained.

SEC. 2. That the objects of the corporation shall be to encourage, in the broadest and most liberal manner, investigation, research, and discovery, and the application of knowledge to the improvement of mankind; and in particular—

(a) To conduct, endow, and assist investigation in any department of science, literature, or art, and to this end to cooperate with governments, universities, colleges, technical schools, learned societies, and individuals.

(b) To appoint committees of experts to direct special lines of research.

(c) To publish and distribute documents.

(d) To conduct lectures, hold meetings, and acquire and maintain a library.

(e) To purchase such property, real or personal, and construct such building or buildings as may be necessary to carry on the work of the corporation.

(f) In general, to do and perform all things necessary to promote the objects of the institution, with full power, however, to the trustees hereinafter appointed and their successors from time to time to modify the conditions and regulations under which the work shall be carried on, so as to secure the application of the funds in the manner best adapted to the conditions of the time, provided that the objects of the corporation shall at all times be among the foregoing or kindred thereto.

SEC. 3. That the direction and management of the affairs of the corporation and the control and disposal of its property and funds shall be vested in a board of trustees, twenty-two in number, to be composed of the following individuals: Alexander Agassiz, John S. Billings, John L. Cadwalader, Cleveland H. Dodge, William N. Frew, Lyman J. Gage, Daniel C. Gilman, John Hay, Henry L. Higginson, William Wirt Howe, Charles L. Hutchinson, Samuel P. Langley, William Lindsay, Seth Low, Wayne MacVeagh, Darius O. Mills, S. Weir Mitchell, William W. Morrow, Ethan A. Hitchcock, Elihu Root, John C. Spooner, Andrew D. White, Charles D. Walcott, Carroll D. Wright, who shall constitute the first board of trustees. The board of trustees shall have power from time to time to increase its membership to not more than twenty-seven members. Vacancies occasioned by death, resignation, or otherwise shall be filled by the remaining trustees in such manner as the by-laws

ARTICLES OF INCORPORATION

shall prescribe; and the persons so elected shall thereupon become trustees and also members of the said corporation. The principal place of business of the said corporation shall be the city of Washington, in the District of Columbia.

SEC. 4. That such board of trustees shall be entitled to take, hold, and administer the securities, funds, and property so transferred by said Andrew Carnegie to the trustees of the Carnegie Institution and such other funds or property as may at any time be given, devised, or bequeathed to them, or to such corporation, for the purposes of the trust; and with full power from time to time to adopt a common seal, to appoint such officers, members of the board of trustees or otherwise, and such employees as may be deemed necessary in carrying on the business of the corporation, at such salaries or with such remuneration as they may deem proper; and with full power to adopt by-laws from time to time and such rules or regulations as may be necessary to secure the safe and convenient transaction of the business of the corporation; and with full power and discretion to deal with and expend the income of the corporation in such manner as in their judgment will best promote the objects herein set forth and in general to have and use all powers and authority necessary to promote such objects and carry out the purposes of the donor. The said trustees shall have further power from time to time to hold as investments the securities hereinabove referred to so transferred by Andrew Carnegie, and any property which has been or may be transferred to them or such corporation by Andrew Carnegie or by any other person, persons, or corporation, and to invest any sums or amounts from time to time in such securities and in such form and manner as are permitted to trustees or to charitable or literary corporations for investment, according to the laws of the States of New York, Pennsylvania, or Massachusetts, or in such securities as are authorized for investment by the said deed of trust so executed by Andrew Carnegie, or by any deed of gift or last will and testament to be hereafter made or executed.

SEC. 5. That the said corporation may take and hold any additional donations, grants, devises, or bequests which may be made in further support of the purposes of the said corporation, and may include in the expenses thereof the personal expenses which the trustees may incur in attending meetings or otherwise in carrying out the business of the trust, but the services of the trustees as such shall be gratuitous.

SEC. 6. That as soon as may be possible after the passage of this Act a meeting of the trustees hereinbefore named shall be called by Daniel C. Gilman, John S. Billings, Charles D. Walcott, Weir Mitchell, John Hay, Elihu Root, and Carroll D. Wright, or any four of them, at the city of Washington, in the District of Columbia, by notice served in person or by mail addressed to each trustee at his place of residence; and the said trustees, or a majority thereof, being assembled, shall organize and proceed to adopt by-laws, to elect officers and appoint committees, and generally to organize the said corporation; and said trustees herein named, on behalf of the corporation hereby incorporated, shall thereupon receive, take over, and enter into possession, custody, and management of all property, real or personal, of the corporation heretofore known as the Carnegie Institution, incorporated, as heretofore set forth under "An Act to establish a Code of Law for the District of Columbia, January fourth, nineteen hundred and two," and to all its rights, contracts, claims,

CARNEGIE INSTITUTION OF WASHINGTON

and property of any kind or nature; and the several officers of such corporation, or any other person having charge of any of the securities, funds, real or personal, books, or property thereof, shall, on demand, deliver the same to the said trustees appointed by this Act or to the persons appointed by them to receive the same; and the trustees of the existing corporation and the trustees herein named shall and may take such other steps as shall be necessary to carry out the purposes of this Act.

SEC. 7. That the rights of the creditors of the said existing corporation known as the Carnegie Institution shall not in any manner be impaired by the passage of this Act, or the transfer of the property hereinbefore mentioned, nor shall any liability or obligation for the payment of any sums due or to become due, or any claim or demand, in any manner or for any cause existing against the said existing corporation, be released or impaired; but such corporation hereby incorporated is declared to succeed to the obligations and liabilities and to be held liable to pay and discharge all of the debts, liabilities, and contracts of the said corporation so existing to the same effect as if such new corporation had itself incurred the obligation or liability to pay such debt or damages, and no such action or proceeding before any court or tribunal shall be deemed to have abated or been discontinued by reason of the passage of this Act.

SEC. 8. That Congress may from time to time alter, repeal, or modify this Act of incorporation, but no contract or individual right made or acquired shall thereby be divested or impaired.

SEC. 9. That this Act shall take effect immediately.

Approved, April 28, 1904

BY-LAWS OF THE INSTITUTION

Adopted December 13, 1904. Amended December 13, 1910, December 13, 1912, December 10, 1937, December 15, 1939, December 13, 1940, December 18, 1942, and December 12, 1947

ARTICLE I

THE TRUSTEES

1. The Board of Trustees shall consist of twenty-four members, with power to increase its membership to not more than twenty-seven members. The Trustees shall hold office continuously and not for a stated term.
2. In case any Trustee shall fail to attend three successive annual meetings of the Board he shall thereupon cease to be a Trustee.
3. No Trustee shall receive any compensation for his services as such.
4. All vacancies in the Board of Trustees shall be filled by the Trustees by ballot at an annual meeting, but no person shall be declared elected unless he receives the votes of two-thirds of the Trustees present.

ARTICLE II

OFFICERS OF THE BOARD

1. The officers of the Board shall be a Chairman of the Board, a Vice-Chairman, and a Secretary, who shall be elected by the Trustees, from the members of the Board, by ballot to serve for a term of three years. All vacancies shall be filled by the Board for the unexpired term; provided, however, that the Executive Committee shall have power to fill a vacancy in the office of Secretary to serve until the next meeting of the Board of Trustees.
2. The Chairman shall preside at all meetings and shall have the usual powers of a presiding officer.
3. The Vice-Chairman, in the absence or disability of the Chairman, shall perform the duties of the Chairman.
4. The Secretary shall issue notices of meetings of the Board, record its transactions, and conduct that part of the correspondence relating to the Board and to his duties.

ARTICLE III

EXECUTIVE ADMINISTRATION

The President

1. There shall be a President who shall be elected by ballot by, and hold office during the pleasure of, the Board, who shall be the chief executive officer of the Institution. The President, subject to the control of the Board and the Executive Committee, shall have general charge of all matters of administration and supervision of all arrangements for research and other work undertaken by the Institution or with its funds. He shall prepare and submit to the Board of Trustees and to the Executive

CARNEGIE INSTITUTION OF WASHINGTON

Committee plans and suggestions for the work of the Institution, shall conduct its general correspondence and the correspondence with applicants for grants and with the special advisers of the Committee, and shall present his recommendations in each case to the Executive Committee for decision. All proposals and requests for grants shall be referred to the President for consideration and report. He shall have power to remove, appoint, and, within the scope of funds made available by the Trustees, provide for compensation of subordinate employees and to fix the compensation of such employees within the limits of a maximum rate of compensation to be established from time to time by the Executive Committee. He shall be *ex officio* a member of the Executive Committee.

2. He shall be the legal custodian of the seal and of all property of the Institution whose custody is not otherwise provided for. He shall sign and execute on behalf of the corporation all contracts and instruments necessary in authorized administrative and research matters and affix the corporate seal thereto when necessary, and may delegate the performance of such acts and other administrative duties in his absence to the Executive Officer. He may execute all other contracts, deeds, and instruments on behalf of the corporation and affix the seal thereto when expressly authorized by the Board of Trustees or Executive Committee. He may, within the limits of his own authorization, delegate to the Executive Officer authority to act as custodian of and affix the corporate seal. He shall be responsible for the expenditure and disbursement of all funds of the Institution in accordance with the directions of the Board and of the Executive Committee, and shall keep accurate accounts of all receipts and disbursements. Following approval by the Executive Committee he shall transmit to the Board of Trustees before its annual meeting in December a written report of the operations and business of the Institution for the preceding fiscal year with his recommendations for work and appropriations for the succeeding calendar year.

3. He shall attend all meetings of the Board of Trustees.

4. There shall be an officer designated Executive Officer who shall be appointed by and hold office at the pleasure of the President, subject to the approval of the Executive Committee. His duties shall be to assist and act for the President as the latter may duly authorize and direct.

5. The President shall retire from office at the end of the calendar year in which he becomes sixty-five years of age.

ARTICLE IV

MEETINGS

1. The annual meeting of the Board of Trustees shall be held in the City of Washington, in the District of Columbia, on the first Friday following the second Thursday of December in each year unless the date and place of meeting are otherwise ordered by the Executive Committee.

2. Special meetings of the Board may be called by the Executive Committee by notice served personally upon, or mailed to the usual address of, each Trustee twenty days prior to the meeting.

3. Special meetings shall, moreover, be called in the same manner by the Chairman upon the written request of seven members of the Board.

BY-LAWS OF THE INSTITUTION

ARTICLE V

COMMITTEES

1. There shall be the following standing Committees, *viz.* an Executive Committee, a Finance Committee, an Auditing Committee, and a Nominating Committee.

2. All vacancies occurring in the Executive Committee, the Finance Committee, the Auditing Committee, and the Nominating Committee shall be filled by the Trustees at the next regular meeting. In case of vacancy in the Finance Committee, the Auditing Committee, or the Nominating Committee, upon request of the remaining members of such committee, the Executive Committee may fill such vacancy by appointment until the next meeting of the Board of Trustees.

3. The terms of all officers and of all members of committees, as provided for herein, shall continue until their successors are elected or appointed.

Executive Committee

4. The Executive Committee shall consist of the Chairman and Secretary of the Board of Trustees and the President of the Institution *ex officio* and, in addition, five trustees to be elected by the Board by ballot for a term of three years, who shall be eligible for re-election. Any member elected to fill a vacancy shall serve for the remainder of his predecessor's term.

5. The Executive Committee shall, when the Board is not in session and has not given specific directions, have general control of the administration of the affairs of the corporation and general supervision of all arrangements for administration, research, and other matters undertaken or promoted by the Institution. It shall also submit to the Board of Trustees a printed or typewritten report of each of its meetings, and at the annual meeting shall submit to the Board a report for publication.

6. The Executive Committee shall have power to authorize the purchase, sale, exchange, or transfer of real estate.

Finance Committee

7. The Finance Committee shall consist of five members to be elected by the Board of Trustees by ballot for a term of three years.

8. The Finance Committee shall have custody of the securities of the corporation and general charge of its investments and invested funds, and shall care for and dispose of the same subject to the directions of the Board of Trustees. It shall have power to authorize the purchase, sale, exchange, or transfer of securities and to delegate this power. It shall consider and recommend to the Board from time to time such measures as in its opinion will promote the financial interests of the Institution, and shall make a report at each meeting of the Board.

Auditing Committee

9. The Auditing Committee shall consist of three members to be elected by the Board of Trustees by ballot for a term of three years.

CARNEGIE INSTITUTION OF WASHINGTON

10. Before each annual meeting of the Board of Trustees, the Auditing Committee shall cause the accounts of the Institution for the preceding fiscal year to be audited by public accountants. The accountants shall report to the Committee, and the Committee shall present said report at the ensuing annual meeting of the Board with such recommendations as the Committee may deem appropriate.

Nominating Committee

11. The Nominating Committee shall consist of the Chairman of the Board of Trustees *ex officio* and, in addition, three trustees to be elected by the Board by ballot for a term of three years, who shall not be eligible for re-election until after the lapse of one year. Any member elected to fill a vacancy shall serve for the remainder of his predecessor's term, provided that of the Nominating Committee first elected after adoption of this By-Law one member shall serve for one year, one member shall serve for two years, and one member shall serve for three years, the Committee to determine the respective terms by lot.

12. Sixty days prior to an annual meeting of the Board the Nominating Committee shall notify the Trustees by mail of the vacancies to be filled in membership of the Board. Each Trustee may submit nominations for such vacancies. Nominations so submitted shall be considered by the Nominating Committee, and ten days prior to the annual meeting the Nominating Committee shall submit to members of the Board by mail a list of the persons so nominated, with its recommendations for filling existing vacancies on the Board and its Standing Committees. No other nominations shall be received by the Board at the annual meeting except with the unanimous consent of the Trustees present.

ARTICLE VI

FINANCIAL ADMINISTRATION

1. No expenditure shall be authorized or made except in pursuance of a previous appropriation by the Board of Trustees, or as provided in Article V, paragraph 8, hereof.

2. The fiscal year of the Institution shall commence on the first day of July in each year.

3. The Executive Committee shall submit to the annual meeting of the Board a full statement of the finances and work of the Institution for the preceding fiscal year and a detailed estimate of the expenditures of the succeeding calendar year.

4. The Board of Trustees, at the annual meeting in each year, shall make general appropriations for the ensuing calendar year; but nothing contained herein shall prevent the Board of Trustees from making special appropriations at any meeting.

5. The Executive Committee shall have general charge and control of all appropriations made by the Board. Following the annual meeting each year, the Executive Committee may make allotment of funds for the period from January 1 to termination of the fiscal year on June 30. It may also make allotment of funds for the period from July 1 to December 31 in advance of July 1. The Committee shall, however, have full authority for allotment of available funds to meet necessary

BY-LAWS OF THE INSTITUTION

expenditures by other methods, if desirable, and for transfer of balances to meet special needs. It shall make provision for outstanding obligations and for reversion of unexpended balances at termination of the fiscal year.

6. The securities of the Institution and evidences of property, and funds invested and to be invested, shall be deposited in such safe depository or in the custody of such trust company and under such safeguards as the Finance Committee shall designate, subject to directions of the Board of Trustees. Income of the Institution available for expenditure shall be deposited in such banks or depositories as may from time to time be designated by the Executive Committee.

7. Any trust company entrusted with the custody of securities by the Finance Committee may, by resolution of the Board of Trustees, be made Fiscal Agent of the Institution, upon an agreed compensation, for the transaction of the business coming within the authority of the Finance Committee.

ARTICLE VII

AMENDMENT OF BY-LAWS

1. These by-laws may be amended at any annual or special meeting of the Board of Trustees by a two-thirds vote of the members present, provided written notice of the proposed amendment shall have been served personally upon, or mailed to the usual address of, each member of the Board twenty days prior to the meeting.

ABSTRACT OF MINUTES OF THE FIFTY-FIRST MEETING OF THE BOARD OF TRUSTEES

The annual meeting of the Board of Trustees was held in Washington, D. C., in the Board Room of the Administration Building, on Friday, December 9, 1949. It was called to order at 10:35 A.M. by the Chairman, Mr. Gifford.

Upon roll call, the following Trustees responded: James F. Bell, Robert Woods Bliss, Lindsay Bradford, W. Cameron Forbes, Walter S. Gifford, Ernest O. Lawrence, Alfred L. Loomis, Robert A. Lovett, Roswell Miller, Henry S. Morgan, Seeley G. Mudd, Henning W. Prentis, Jr., Elihu Root, Jr., Henry R. Shepley, Charles P. Taft, Juan T. Trippe, and James W. Wadsworth. The President of the Institution, Vannevar Bush, was also present.

The minutes of the fiftieth meeting were approved as printed and submitted to the members of the Board.

Reports of the President, the Executive Committee, the Finance Committee, the Auditor, the Auditing Committee, and the Nominating Committee, and of the heads of Divisions and Departments and Research Associates of the Institution were presented and considered.

The sum of \$1,630,478 was appropriated for expenditure by the Institution under the general charge and control of the Executive Committee.

Vacancies in the membership of the Board of Trustees caused by the death of James Forrestal and by the resignations of Frederic A. Delano and Herbert Hoover were filled by the election of Omar N. Bradley, Caryl P. Haskins, and Barklie Henry.

Henning W. Prentis, Jr., was elected a member of the Executive Committee for the term ending in 1950 to succeed the late Frank B. Jewett. Roswell Miller was elected Chairman of the Auditing Committee to succeed Mr. Delano for the term ending in 1951. Lindsay Bradford was elected a member of the Nominating Committee for a period of three years, succeeding Henry S. Morgan.

The meeting adjourned at 12:08 P.M.

REPORT OF THE EXECUTIVE COMMITTEE

FOR THE YEAR ENDED JUNE 30, 1949

To the Trustees of the Carnegie Institution of Washington:

GENTLEMEN: In accordance with the provisions of the By-Laws, the Executive Committee submits this report to the annual meeting of the Board of Trustees.

The detailed record of the activities of the Institution is presented in the reports from the Departments and Divisions, which are contained in the Year Book, a review of some of the highlights being given in the report of the President. The estimate of expenditures for the calendar year 1950 contained in the report of the President has been considered and approved by the Executive Committee, and the Committee has also provisionally approved and recommends to the Board the proposed budget based thereon.

The Board of Trustees at its meeting of December 10, 1948, appointed the firm of Haskins & Sells to audit the accounts of the Institution for the fiscal year ending June 30, 1949. The report of the Auditor, including a balance sheet showing assets and liabilities of the Institution on June 30, 1949, is submitted as a part of the report of the Executive Committee.

In addition to the report of the Auditor there is also submitted a financial statement for the fiscal year ended June 30, 1949, showing funds available for expenditure and amounts allotted by the Executive Committee, and the customary statement of aggregate receipts and disbursements, together with a schedule of real estate and equipment. These statements together with the tables in the Auditor's report comprise the statement of the finances of the Institution.

Three vacancies exist in the membership of the Board of Trustees, resulting from the death in May 1949 of James Forrestal and the resignations of Herbert Hoover in September 1949 and Frederic A. Delano in October 1949.

The term of Mr. Morgan as a member of the Nominating Committee will end at the annual meeting, and a vacancy has resulted in the membership of the Auditing Committee because of the resignation of Mr. Delano.

WALTER S. GIFFORD, *Chairman*
ROBERT WOODS BLISS
VANNEVAR BUSH
FRANK B. JEWETT
HENRY S. MORGAN
ELIHU ROOT, JR.
HENRY R. SHEPLEY
LEWIS H. WEED

October 20, 1949

FINANCIAL STATEMENT FOR THE YEAR ENDED JUNE 30, 1949

	Balances available June 30, 1948	Trustees' appropriations	Net allotments and transfers	Other credits	Total available	Expenditures	Balances available June 30, 1949 for Expenditure Allotment
Administration	\$6,129 85	\$126,750 00	\$10,670 19	\$55 98	\$143,606 02	\$140,407 51	\$3,198 51
Carnegie Corporation Emergency Fund	115,900 41				115,900 41		\$115,900 41
General Contingent Fund ^a	351,460 18	101,600 00	-78,104 63		374,955 55		374,955 55
General Operations	9,032 00	70,790 00	-59,684 29	715 00	20,852 71		20,852 71
Harriet H. Mavor Relief Fund	9,750 00				9,750 00	650 00	9,100 00
Pension Fund	187,974 09	95,000 00	7,100 23		290,074 32	110,763 85	179,310 47
General Publications	17,478 88		30,000 00	9,265 64	86,744 52	31,387 68	45,402 87
Office of Publications	5,711 68	35,550 00	832 71		42,094 39	36,221 86	5,872 53
Research Projects, Fellowships, Grants, etc.	166,892 08		95,024 48	42,200 00	304,116 56	99,033 95	186,090 94
Special Reconversion Fund	12,630 81		-12,630 81				18,971 67
Departmental Research Operations:							
Plant Biology	16,644 62	86,100 00	-4,885 93		97,858 69	87,663 68	10,195 01
Genetics	29,015 95	132,995 00	704 75	32,881 18	195,596 88	175,478 08	20,118 80
Geophysical Laboratory	18,703 15	201,785 00	2,199 52	150 74	222,838 41	212,179 09	10,659 32
Historical Research	4,774 15	124,213 00	-242 10		128,745 05	118,251 22	10,493 83
Mount Wilson Observatory	22,317 48	248,400 00	-15,838 24	980 86	255,860 10	238,692 63	17,167 47
Terrestrial Magnetism	28,563 45	272,750 00	25,723 80	12 44	327,049 69	298,639 57	28,410 12
Embryology	9,394 27	100,853 00	-514 59	11,425 00	120,857 68	118,153 73	2,703 95
	\$1,042,073 05	\$1,596,786 00	\$355 09	\$97,686 84	\$2,736,900 98	\$1,667,542 85	\$528,723 82
							\$540,634 31

AGGREGATE CASH RECEIPTS AND DISBURSEMENTS FROM ORGANIZATION JANUARY 28, 1902, TO JUNE 30, 1949

RECEIPTS		DISBURSEMENTS	
<i>Securities Sold or Redeemed</i>	\$141 088 600 74	<i>Securities Purchased</i>	\$156 964,217 81
<i>Income from Securities and Bank Balances</i>	59 250 958 04	<i>Accrued Interest on Securities Purchased</i>	795,206 16
<i>Proceeds from Sale of Stock Dividends</i>	124 545 40	<i>Pension Fund</i>	2,052 688 22
<i>Sales of Publications</i>	401 513 16	<i>Bickel Fund</i>	90 38
<i>Bickel Fund (Bequest)</i>	300 00	<i>General Reserve Fund</i>	30 477 43
<i>Colburn Fund (Bequest)</i>	52 015 74	<i>Insurance Fund</i>	140 532 24
<i>Hale Relief Fund (Gift)</i>	2 382 28	<i>Harriman Fund</i>	346 44
<i>Harkavy Fund (Gift)</i>	3 050 00	<i>Harrist H. Mayor Relief Fund</i>	900 00
<i>Harriman Fund (Sale of Land)</i>	4 043 70	<i>Harkavy Fund</i>	221 20
<i>Teeple Fund (Bequest)</i>	10 888 42	<i>Special Emergency Reserve Fund</i>	63,819 41
<i>Van Gelder Fund (Bequest)</i>	1 278 58	<i>National Defense Revolving Fund</i>	3 062,974 97
<i>Carnegie Corporation of New York (Endowment Increase and for Specific Purposes)</i>	13 759 381 24	<i>General Contingent Fund</i>	342 289 26
<i>From Other Organizations and Individuals for Specific Purposes</i>	545 885 98	<i>Carnegie Corporation of New York Emergency Fund</i>	101,444 77
<i>Pension Fund (Refunds)</i>	101 482 47	<i>Administration Building and Addition</i>	
<i>General Reserve Fund</i>	79 966 54	<i>Construction and Site (Old Building)</i>	309,915 69
<i>Insurance Fund (Refunds)</i>	13 076 02	<i>Construction (Addition to Administration Bldg.)</i>	416,206 07
<i>National Defense Revolving Fund (Refunds and Advances)</i>	3 095 347 20	<i>Site (Addition to Administration Building)</i>	68,570 96
<i>Administration Building Addition Account Rentals and Refunds</i>	18 021 09	<i>Miscellaneous Expenditures*</i>	40 825 37
<i>Employees Salary Deductions for the Purchase of U. S. Bonds</i>	99 353 65	<i>Departmental Research Operations</i>	3 286 525 81
<i>Miscellaneous Refunds and Receipts</i>	1 205 222 32	<i>Departments of Research Buildings and Equipment</i>	38 703,980 72
		<i>Departmental Operations</i>	5,731,433 48
		<i>Research Projects Fellowships Grants etc</i>	3,201,947 29
		<i>Publication</i>	3,457,360 70
		<i>Employees U. S. Bond Purchases</i>	99,224 40
		<i>National Research Council</i>	150,000 00
		<i>Miscellaneous</i>	28,108 36
		<i>June 30 1949 Cash in Banks</i>	\$219 049,307 14
			808 006 33
			\$219,857,313 47

*Includes Equipment \$7 206 41 Repairs and Alterations to Old Building \$18 599 29

REAL ESTATE AND EQUIPMENT, ORIGINAL COST

JUNE 30, 1949

Administration

1530 P Street, N.W., Washington 5, D. C.

Building and site	\$797 633 96	
Equipment	19 920 73	\$817,554 69

Division of Plant Biology

Stanford, California

Buildings and grounds	\$73 229 67	
Laboratory apparatus	40 913 65	
Library	23 340 81	
Operating equipment	18 991 99	156 476 12

Department of Embryology

Wolfe and Madison Streets, Baltimore 5, Maryland

Laboratory apparatus	\$25 358 38	
Library	7,976 34	
Operating equipment	5 311 21	38 645 93

Department of Genetics

Cold Spring Harbor, Long Island, New York

Buildings and grounds	\$275,734 60	
Laboratory apparatus	49 448 17	
Library	65 256 59	
Operating equipment	26 474 74	416 914 10

Geophysical Laboratory

2801 Upton Street, N.W., Washington 8, D. C.

Buildings and grounds	\$170 383 79	
Laboratory apparatus	140,232 39	
Library	36 510 70	
Operating equipment	39 439 34	386 566 22

Division of Historical Research

10 Irisbie Place, Cambridge 38, Massachusetts

Library	\$10 408 05	
Operating equipment	18 891 38	29 299 43

Mount Wilson Observatory

813 Santa Barbara Street Pasadena 4, California

Buildings and grounds	\$268 629 81	
Instruments	539,722 36	
Library	69,726 52	
Operating equipment	62 489 81	
Hooker 100-inch reflector	641 070 49	1 581,638 99

Department of Terrestrial Magnetism

5241 Broad Branch Road, N.W., Washington 15, D. C.

Buildings and grounds	\$400,311 53	
Laboratory apparatus	176,696 93	
Library	35,651 64	
Operating equipment	64,324 92	676,985 02

\$4 104,080 50

ACCOUNTANTS' CERTIFICATE

To the Board of Trustees of Carnegie Institution of Washington:

We have examined the balance sheet (and supporting schedule of securities owned) of Carnegie Institution of Washington as of June 30, 1949 and the related statements of income and expenditures and current funds surplus for the year then ended. Our examination was made in accordance with generally accepted auditing standards, and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances, except that we did not examine the records in support of expenditures made (approximately \$193,000) by five of the seven branch offices of the Institution, but we have reviewed internal audit reports of the Bursar's office covering examinations of all branch records during the year.

Effective as of July 1, 1948 the Institution adopted the policy of recording proceeds from sales of non-cash dividends, and in any case where the non-cash dividend is retained as an investment its market value on date of receipt, as income. However, generally accepted accounting principles do not recognize ordinary stock dividends as income. Therefore, proceeds of \$109,071.83 from sales of non-cash dividends during the year under review should not be taken into account as dividend income; the other non-cash distributions sold, amounting to \$15,473.57, are properly considered as dividend income.

In our opinion, subject to the exceptions stated above with respect to the limitation of the scope of our examination and the inclusion of the proceeds from the sales of ordinary stock dividends as income, the accompanying balance sheet and statements of income and expenditures and current funds surplus present fairly the financial position of the Institution at June 30, 1949 and the results of its operations for the year then ended, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding period.

HASKINS & SELLS

October 24, 1949

BALANCE SHEET JUNE 30, 1949

ASSETS

<i>Current Funds</i>	
General	\$475 476 01
Cash in banks and on hand	12 424 09
Advances—Departmental Research Operations	868 27
Accounts receivable—other	146 366 30
Inventory—books	15 356 88
Deferred charges	
Due from Endowment and Other Special Funds	377 963 93
	\$1 028 455 43

LIABILITIES

<i>Current Funds</i>	
General	\$273 25
Accounts payable	
Reserve for valuation of books and accounts receivable	147 234 52
Current Funds surplus	
Reserves for unexpended appropriations	\$3 198 51
Administrational	
Departmental Research	99 748 50
Operations	20 852 71
Publication	61 229 37
Research Projects, Fellowships, Grants, etc.	205 062 61
Total	\$390 091 70

Other reserves	
Carnegie Corporation	115 900 41
Emergency Fund	374 955 55
General Contingent Fund	
	880 947 66

Restricted	
Buckel Fund	\$209 62
Harkavy Fund—income account	195 31
Harriman Fund—income account	84 128 07
	84 533 00
	\$1 112 968 43

Endowment and Other Special Funds
 Cash in banks
 Securities (approximate market value \$41 916 000)

Bonds	\$9 027 873 15
U. S. Government	
Federal Reserve Bank and International	
Public utility	853 288 88
Communication	2 300 223 90
Railroad	1 168 405 65
Railroad equipment trust	274 484 45
Industrial and miscellaneous	877 386 21
Stocks	5 225 725 79
Preferred	3 980 855 10
Common	16 930 579 91
	40 638 821 04
	40 092 009 9*

Endowment and Other Special Funds
 Due to Current Funds

Capital Fund—Endowment Fund	\$32 000 000 00
Capital Fund—General Reserve Fund	5 645 235 43
Colburn Fund	103 310 80
Harkavy Fund	2 828 80
Harriman Fund	304 043 70
Teagle Fund	10 888 42
Van Gelder Fund	1 278 58
Special Funds	
General Reserve Fund	2 140 012 86
General Reserve Fund	3 491 58
Harcourt H. Maxon Relief Fund	9 100 00
Harcourt H. Maxon Relief Fund	179 310 47
Pension Fund	124 545 40
Special Income Reserve	40 524 046 04
	40 902 009 97
	\$377 963 93

Plant Funds

Income invested in plant*	\$3 929 591 43
Harriman property (gift)	154 416 07
Harkavy property (gift)	2 070 00
Special Funds (Harkavy gifts) (equipment valued at \$20 803 39 included above*)	
Buckel property (bequest) (nominal value)	38 000 60
	1 00
	4 104 080 50
	\$46 119 078 90

Plant Funds
 Invested in real estate and equipment
 Office of Administration
 Departments of Research

TOTAL

*Represents proceeds from sale of non-cash dividend-

STATEMENT OF INCOME AND EXPENDITURES FOR THE YEAR ENDED JUNE 30, 1949

INCOME

Investment income

Interest and dividends on securities
Less—Amortization of bond premiums

\$1,694,577 46
 11,858 35

\$1,682,719 11

Proceeds from sale of stock dividends

124 545 40 \$1,807,264 51

Less—Income allocated to

Special Income Reserve

\$124,545 40

General Reserve Fund

85,449 25

Pension Fund

350 23

George E. Hale Relief Fund

17 00

Harkavy Fund

116 63

210,478 51

NET INVESTMENT INCOME APPROPRIATED FOR CURRENT PURPOSES

\$1,596,786 00

Other income

Sales of publications

\$9,050 87

American Cancer Society—grants

23,062 00

Carnegie Corporation of New York—grants

42 000 00

Dormitory and mess hall

9 651 68

Bickel property

\$300 00

Less—Maintenance expenses

90 38

209 62

Estate of John E. Teeple (deceased)

48 66

George E. Hale Relief Fund

3,474 58

Life Insurance Medical Research Fund

1 000 00

U. S. Public Health Service—grants

9,125 00

Miscellaneous

9 204 39

Total

\$106,826 80

Less—Amounts credited to

Restricted funds

\$209 62

General Reserve Fund

6 402 24

Special funds

3 523 24

10 135 10

96 691 70

TOTAL INCOME*

\$1 693 477 70

EXPENDITURES

Pension Fund—annuity and insurance

\$110 763 85

Harriet H. Mayor Relief Fund

650 00

Departmental Research Operations

Salaries

\$929 770 45

Operating expenses

308 353 17

Dormitory and mess hall—salaries

3 386 00

Dormitory and mess hall—operating expenses

7 548 38

1 249,058 00

Research Projects, Fellowships, Grants, etc

Salaries

\$13 536 90

Grants and miscellaneous

32,125 70

Fellowship program

53 391 35

99,053 95

Office of Publications

Printing and publishing expenses

\$31 387 68

Office expenses

Salaries

29 376 77

Stationery, postage, etc

6 845 09

67,609 54

Administration

140 407 51

TOTAL EXPENDITURES

1 667 542 85

Excess of income over expenditures

\$25,934 85

*Does not include net gain from sales and redemptions of securities shown in summary of security transactions page xxxvi

STATEMENT OF CURRENT FUNDS SURPLUS FOR THE YEAR ENDED JUNE 30, 1949

Balance, July 1, 1948

\$844 348 96

Additions

Transfers from

Harriman Fund

\$1,000 00

Pension Fund

9,013 85

Harriet H. Mayor Relief Fund

650 00

Excess of income over expenditures

25 934 85

36,598 70

Balance, June 30, 1949

\$880,947 66

SCHEDULE OF SECURITIES OWNED JUNE 30, 1949

Principal amount	Description	Maturity	Cost, amortized cost, or value at date acquired	Approximate market value	Net income
UNITED STATES GOVERNMENT BONDS					
\$500,000	U. S. of America Treasury Cert. of Ind 1 ^{1/2} s	1-3-50	\$500,146 98	\$500,360	—\$34.25
304,000	U. S. of America Treasury 2s	1951-49	304,000 00	304,475	6,080.00
312,000	U. S. of America Treasury 2s	1951-49	312,000 00	313,463	6,240.00
100,000	U. S. of America Treasury 2s	1952-50	200,000 00	201,188	4,000.00
4,500,000	U. S. of America Treasury 2 ^{1/2} s	1953-52	4,500,000 00	4,599,884	90,000.00
800,000	U. S. of America Treasury 2 ^{1/2} s	1953-52	800,000 00	800,000 00	16,000.00
400,000	U. S. of America Treasury 2 ^{1/2} s	1953-52	400,000 00	417,750	9,000.00
1,239,000	U. S. of America Treasury 2 ^{1/2} s	1954-52	1,241,048 67*	1,278,106	30,975.00
50,000	U. S. of America Savings Series "G" 2 ^{1/2} s	1953	50,000 00	48,350	1,250.00
50,000	U. S. of America Savings Series "G" 2 ^{1/2} s	1954	50,000 00	48,200	1,250.00
50,000	U. S. of America Savings Series "G" 2 ^{1/2} s	1954	50,000 00	48,050	1,250.00
100,000	U. S. of America Savings Series "G" 2 ^{1/2} s	1955	100,000 00	95,800	2,500.00
100,000	U. S. of America Savings Series "G" 2 ^{1/2} s	1955	100,000 00	95,200	2,500.00
100,000	U. S. of America Savings Series "G" 2 ^{1/2} s	1956	100,000 00	95,000	2,500.00
100,000	U. S. of America Savings Series "G" 2 ^{1/2} s	1956	100,000 00	94,800	2,500.00
100,000	U. S. of America Savings Series "G" 2 ^{1/2} s	1958	100,000 00	94,800	2,500.00
100,000	U. S. of America Savings Series "G" 2 ^{1/2} s	1959	100,000 00	95,600	2,500.00
100,000	U. S. of America Savings Series "G" 2 ^{1/2} s	1960	100,000 00	98,800	1,250.00
Income from bonds redeemed					4,245.33
\$9,005,000	Total U. S. Government		\$9,027,873.15	\$9,155,626	\$186,006.08
FOREIGN AND INTERNATIONAL BANK BONDS					
\$100,000	Australia, Commonwealth of, S. F. 3 ^{1/2} s	1956	\$100,000 00	\$94,000	\$3,250.00
50,000	Australia, Commonwealth of, S. F. 3 ^{1/2} s	1957	48,750 00	47,000	1,625.00
90,000	Canadian National Ry. Co. 4 ^{1/2} s Guar	1951	90,001 47*	94,500	4,050.00
100,000	Canadian National Ry. Co. 4 ^{1/2} s Guar	1957	112,000 30*	114,000	3,500.00
35,000	Canadian National Ry. Co. 5s Guar	1970	37,354.52*	37,100	1,750.00
100,000	International Bank for Reconstruction and Development 2 ^{1/2} s	1957	100,000 00	100,750	2,250.00
200,000	Shawinigan Water & Power Co., 1st Mtg. & Coll. Tr. S. F. 3s	1971	207,920 00*	196,000	6,000.00
100,000	City of Toronto Cons. Loan Deb 5s	1949	96,164.59	101,000	5,000.00
\$832,000	Total Foreign and International Bank		\$853,288.88	\$844,200	\$31,275.00

*After deduction for amortization of premiums on bonds purchased subsequent to January 1, 1940

SCHEDULE OF SECURITIES OWNED JUNE 30, 1949—Continued

Principal amount	Description	Maturity	Cost, amortized cost, or value at date acquired	Approximate market value	Net income
PUBLIC UTILITY BONDS					
\$241,000	Columbus & Southern Ohio Electric Co., 1st Mtg 3½s	1970	\$254,705 08*	\$257,870	\$7,832 50
300,000	Consolidated Natural Gas Co., Deb 2½s	1958	300,832 60*	307,000	8,250 00
100,000	Detroit Edison Co., Conv. Deb 3s	1963	105,242 99*	106,000	1,250 00
37,000	Greyhound Corporation, Deb 3s	1959	37,313 83*	37,370	1,110 00
200,000	Indiana Power & Light Co., 1st Mtg 3½s	1975	204,338 69*	204,000	6,250 00
200,000	Indiana Power & Light Co., 1st Mtg 3½s	1968	101,500 00	106,000	3,250 00
97,000	Oklahoma Natural Gas Co., 1st Mtg 3½s	1961	98,056 57*	97,970	2,788 75
100,000	Panhandle Eastern Pipe Line Co., S F Deb 3½s	1973	101,743 82*	104,000	2,217 17
50,000	Philadelphia Electric Co., 1st & Ref Mtg 2½s	1978	51,687 87*	51,000	1,687 75
209,000	Philadelphia Electric Power Co., 1st Mtg 2½s	1975	211,552 32*	206,000	5,433 75
200,000	Public Service Co. of Indiana Inc., 1st Mtg 3½s	1975	204,358 12*	206,000	6,250 00
125,000	Puget Sound Power & Light Co., 1st Mtg 4½s	1972	129,128 38*	131,250	5,312 50
216,000	Tennessee Gas & Transmission Co., 1st Mtg Pipe Line 2½s	1966	218,754 00*	211,680	5,940 00
283,000	United Gas Corp., 1st Mtg & Coll Tr 2½s	1967	283,000 00	283,000	7,782 50
Income from bonds redeemed					
<u>\$2,256,000</u>	<u>Total Public Utility</u>		<u>\$2,300,223 90</u>	<u>\$2,303,930</u>	<u>\$63,438 67</u>
COMMUNICATION BONDS					
\$150,000	American Telephone & Telegraph Co., Conv. Deb 2½s	1961	\$155,378 55*	\$153,000	\$4,125 00
150,000	American Telephone & Telegraph Co., Deb 2½s	1975	152,418 75*	147,000	4,125 00
5,000	American Telephone & Telegraph Co., Deb 3½s	1959	45,000 00	49,050	
200,000	American Telephone & Telegraph Co., Deb 3½s	1978	201,680 00*	208,000	6,250 00
100,000	New York Telephone Co., Ref Mtg 3½s	1978	101,380 69*	105,000	3,125 00
200,000	Pacific Telephone & Telegraph Co., Deb 3½s	1978	205,297 66*	210,000	6,500 00
300,000	Southwestern Bell Telephone Co., Deb 3½s	1983	307,250 00*	318,000	9,375 00
Income from bonds called					
<u>\$1 145,000</u>	<u>Total Communication</u>		<u>\$1,168 405 65</u>	<u>\$1,190,050</u>	<u>\$36,100 00</u>
RAILROAD BONDS					
\$100,000	Chesapeake & Ohio Ry. Co., Gen Mtg 4½s	1992	\$99,464 29	\$124,000	\$4,500 00
75,000	Chicago & W. Indiana R. R. Co., Cons 4s	1952	70,357 66	77,250	3,000 00
100,000	Pennsylvania R. R. Co., Cons Mtg 4½s	1960	104,662 50	114,000	4,500 00
Income from bonds sold					
<u>\$275,000</u>	<u>Total Railroad</u>		<u>\$274 484 45</u>	<u>\$315,250</u>	<u>\$12,006 39</u>

*After deduction for amortization of premiums on bonds purchased subsequent to January 1 1940

SCHEDULE OF SECURITIES OWNED JUNE 30, 1949—Continued

Principal amount	Description	Maturity	Cost, amortized cost, or value at date acquired	Approximate market value	Net income
RAILROAD EQUIPMENT TRUST BONDS					
\$150,000	Chesapeake & Ohio Ry. Co., Eq. Tr. 2s	1956-58	\$146,340.34	\$146,500	\$3,000.00
300,000	Chicago Burlington & Quincy R. R. Co., Eq. Tr. 2½s	1958-63	292,507.12	293,500	6,750.00
150,000	Pennsylvania R. R. Co., Eq. Tr. 2½s Guar.	1958-62	146,358.96	145,500	3,562.50
150,000	Southern Pacific Co., Eq. Tr. 2½s	1958-61	146,218.16	145,500	3,187.50
150,000	Southern Railway Co., Eq. Tr. 2½s	1956-58	145,928.69	145,500	3,187.50
\$900,000	Total Railroad Equipment Trust		\$877,386.21	\$877,000	\$19,687.50
INDUSTRIAL AND MISCELLANEOUS BONDS					
\$200,000	American Tobacco Co., Deb. 3s	1969	\$203,051.12*	\$208,000	\$6,000.00
240,000	Bristol Myers Co., Deb. 3s	1968	241,146.90*	247,200	7,200.00
150,000	Evco & Mayfield Co., Inc., S. F. Deb. 2½s	1965	152,116.90*	154,000	1,840.00
153,000	Food Machinery Corp., S. F. Deb. 2½s	1965	155,428.99*	158,160	6,720.00
193,000	Goodrich (B. F.) Company, 1st Mtg. 2½s	1962	192,308.98	188,160	3,825.00
291,000	P. Lorillard Co., Deb. 3s	1963	301,184.24*	303,000	8,250.00
300,000	National Dairy Products Corp., Deb. 2½s	1963	300,041.08*	299,730	8,750.00
400,000	Phillips Petroleum Co., S. F. Deb. 2½s	1970	304,403.52*	300,000	8,250.00
23,000	Pittsburgh Consolidation Coal Co., Deb. 3½s	1964	403,353.13*	407,960	11,000.00
150,000	Quaker Oats Co., Deb. 2½s	1965	151,865.43*	151,000	3,937.50
300,000	Shelton (Joseph E.) & Sons, Inc., Deb. 2½s	1966	298,500.00	282,000	7,500.00
400,000	Standard Oil Co. of California, Deb. 2½s	1971	405,236.36*	388,000	10,000.00
400,000	Standard Oil Co. of California, Deb. 2½s	1976	390,278.75	384,000	10,000.00
400,000	Swift & Co., Deb. 2½s	1966	410,219.39*	408,000	11,000.00
400,000	Texas Corporation, Deb. 3s	1972	301,651.89*	294,000	7,875.00
400,000	Union Oil Company of California, Deb. 2½s	1965	420,341.89*	420,000	12,000.00
250,000	United States Rubber Co., Deb. 2½s	1970	258,959.88*	252,000	9,625.00
100,000	Westinghouse Electric Corporation, Deb. 2½s	1976	100,372.09*	98,000	9,625.00
300,000	Westinghouse Electric Corporation, Deb. 2½s	1971	302,064.29*	297,000	7,875.00
Income from bonds called					
					157.50
\$5,163,000	Total Industrial and Miscellaneous		\$5,725,723.79	\$5,164,620	\$142,465.00
\$19,576,000	Bonds—Funds Invested		\$19,727,386.03	\$19,850,676	\$490,978.64

*After deduction for amortization of premiums on bonds purchased subsequent to January 1 1940.

Number of shares	Description	PREFERRED STOCKS
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COMMON STOCKS

(Continued on following page)

SCHEDULE OF SECURITIES OWNED JUNE 30, 1949—Continued

Number of shares	Description	Cost, amortized cost, or value at date acquired	Approximate market value	Net income	COMMON STOCKS—Continued
1,600	Coca-Cola Company	\$233,577 80	\$208,000	\$7,300 00	
2,000	Commercial National Bank and Trust Co of N Y	86,522 22	84,000	4,000 00	
6,396	Commonwealth Edison Company	196,326 62	158,900	9,375 10	
2,000	Consolidated Edison Company of N Y	67,530 37	46,000	3,200 00	
1,300	Consolidated Gas Electric Light and Power Company of Baltimore	108,423 09	79,300	4,500 00	
1,200	Continental Illinois National Bank & Trust Co of Chicago	260,277 60	86,400	4,800 00	
5,400	Continental Oil Co of Delaware	388,856 82	318,420	13,850 00	
9,900	Delaware Power & Light Company	105,714 47	534,600	31,900 00	
5,100	DuPont (E. I.) de Nemours & Co	506,088 07	96,900	5,610 00	
12,400	Eastman Kodak Co	458,548 61	570,400	33,325 00	
13,100	Fidelity Fund Insurance Co	121,050 00	524,000	21,615 00	
1,710	Ford Machinery and Chemical Corporation	177,575 97	131,670	4,047 00	
5,188	Food Machinery and Chemical Corporation	121,050 00	124,512	8,280 50	
13,700	General Electric Co	317,875 40	479,500	25,830 00	
17,700	General Foods Corporation	347,855 46	319,200	16,650 00	
8,400	General Motors Corporation	447,819 07	470,400	45,800 00	
400	Guaranty Trust Co. of N. Y.	98,003 91	104,800	4,800 00	
8,700	Gulf Oil Corp	391,540 45	513,300	25,500 00	
2,000	Hartford Fire Insurance Co	179,826 06	238,000	5,000 00	
8,700	Humble Oil & Refining Co	290,411 57	600,300	38,250 00	
3,475	Insurance Company of North America	255,748 31	347,500	11,043 75	
2,950	International Business Machines Corp	219,994 84	445,450	11,800 00	
7,200	Johns-Manville Corp.	148,016 12	140,000	7,350 00	
4,000	Kearney & Fayerweather Corporation	362,303 69	324,000	26,500 00	
7,300	Kresge (S. S.) Company	230,158 25	284,700	13,600 00	
2,100	Liggett & Myers Tobacco Co	189,977 30	170,100	10,500 00	
320	Mellon National Bank and Trust Company	67,193 07	86,400	2,880 00	
6,750	Middle South Utilities, Inc	99,683 97	101,250	6,850 00	
3,700	Minneapolis-Honeywell Regulator Co	147,869 94	156,800	19,200 00	
9,700	Minnesota Chemical Co	394,552 93	485,000	19,200 00	
3,000	Monogram Ward & Co	161,894 89	144,000	9,000 00	
7,700	National Cash Register Co	267,801 00	246,400	18,250 00	
1,900	National City Bank of New York	76,087 50	74,100	7,720 00	
1,800	National Union Fire Insurance Co	62,056 90	55,800	2,520 00	
10,800	Newberry (J. J.) Co	143,047 69	334,800	21,600 00	
3,900	New Jersey Zinc, Co	265,862 52	221,400	15,725 00	
2,750	Owens-Illinois Glass Co	201,480 00	151,400	11,400 00	
3,900	Pacific Gas & Electric Company	131,073 09	85,250	5,500 00	
11,000	Pennsylvania Electric Company	397,461 99	526,400	27,500 00	
1,000	Pennsylvania Gas Light and Coke Company	106,350 00	100,000	5,875 00	
3,700	Pfizer (Chas.) & Co, Inc	215,210 63	170,200	9,625 00	
3,500	Philadelphia Electric Company	100,048 39	77,000	4,200 00	
7,600	Phillips Petroleum Co	406,186 99	402,800	22,600 00	
9,700	Pittsburgh Plate Glass Co	312,977 21	300,700	16,275 00	
2,200	Procter & Gamble Co	125,493 18	134,200	6,300 00	
1,800	Reynolds (R. J.) Tobacco Co "B	168,100 00	168,000	2,800 00	
1,400	Scott Paper Co	106,987 02	112,000	2,950 00	
2,900	Shaw-Walker & Co	103,055 95	126,500	5,335 00	
16,400	St. Paul Fire and Marine Insurance Co	374,427 57	623,200	45,100 00	
5,000	Shaw-Walker & Co	399,644 64	363,000	18,975 00	
5,000	Southern California Edison Company, Ltd	175,996 33	155,000	3,750 00	
11,300	Standard Oil Co of Indiana	409,733 33	418,100	21,850 00	

(Continued on following page)

REPORT OF THE PRESIDENT

OF THE

CARNEGIE INSTITUTION OF WASHINGTON

As this annual report is presented to the Trustees in accordance with the By-Laws, the Institution continues to pursue its program of fundamental research. The past year has brought the accomplishment summarized in the annual reports of the Departments, a few of the highlights of which are mentioned below.

In recent reports the way in which scientific programs become formulated by the staffs of the Departments of the Institution has been discussed. There has also been some consideration of the relationship of the Board of Trustees to the programs of an institution of this sort. It would perhaps be well, therefore, to write briefly this year of the position of an individual investigator within the Institution, and the relationship of his program to the whole.

We do not have a rigid hierarchy in our staff. There are senior investigators, junior investigators, aids, and technical supporters of many sorts, but even the titles vary from one Department to another, and there is little of rigidity in the whole structure. This is a desirable situation, for the extraordinary informality of our internal relationships, characteristically American, is one of our great assets. Certainly we have under one title or another senior staff members who, by reason of their attainments, have earned the right to go their own way on their researches, and to explore those puzzles of our environment which most intrigue them. Indeed, the entire organization revolves about the work of these men; the Institution exists in order that they may have the rare opportunity which they

enjoy. Junior investigators in general work in collaboration with these individuals, but with a great deal of freedom of their own and certainly with the opportunity to pursue their own problems to a very considerable extent and thus demonstrate their own effectiveness. The team is completed by younger staff members who have not as yet arrived at the point of independence, together with the technical staff which is most decidedly an integral part of the structure. There are no age requirements, nor are there any seniority rules or scheduled promotions in the whole organization.

The question then naturally arises how the performance of the senior staff is measured. In the large, the answer to this question is that their performance is measured in the same manner that scientific accomplishment generally is measured under the best conditions in any scientific community, namely by the consensus of opinion of colleagues, and of investigators in the same general field who are located elsewhere. But there are certain negative aspects of this subject which are well worth mentioning. Only too often in research organizations the product is weighed, sometimes almost literally, and the staff are under pressure to produce results at intervals, which are not stated explicitly but well understood. When a man is considered for a scientific position or for election to a learned body, only too frequently the number of his published papers is counted, and it is carefully noted whether he has published regularly. The sort of artificial pressure which this tendency creates is absent from

CARNEGIE INSTITUTION OF WASHINGTON

the Institution. The staff all recognize, of course, that the man who shirks the sometimes disagreeable job of getting his results promptly into print is neglecting an essential part of his undertaking. But the staff also recognize that one good solid article that really constitutes a milestone is worth any number of dribbles, that the article that really pins a subject down completely is far better than the one that is rushed into print while still wobbly in its reasoning. Moreover, the staff recognize that there is such a thing as luck in research, and that the best of investigators may at times miss an opportunity, and struggle long and deviously before he emerges from a temporary obscurity. In fact, the absence of pressure for periodic public performance is one of the strongest reasons why the staff of the Institution are enthusiastic scientists. We take pride in the fact that the stature of our scientists is an affair of a lifetime, and no matter of flashy performance. Yet there is no doubt that the staff regard very seriously the obligation and responsibility that are theirs, because of the rare opportunity they have to advance the sum of human knowledge without arbitrary or artificial pressures or distractions.

The world of science has a place for almost every sort of individual. At the one extreme there are those gregarious co-operative types who can operate more effectively in concert and who become important individuals in a group attack upon a particularly knotty subject. At the other extreme are those detached lonely workers who simply must pursue their own affairs by themselves, without collaboration, and sometimes in the extreme even without assistance. The Institution does not have much of the type of organized group attack which is necessary and sometimes very effective in applied research,

particularly in great commercial laboratories. Neither, on the other hand, do we seem to produce the type of genius who can operate only in isolation. Without definite planning in that regard, our staff, for all its variety, lies somewhere between these two extremes. We expect, and by this we mean that staff opinion expects, that the individual who is pursuing his own line of research will so select his problems and so conduct them that his pursuit of them will reflect favorably upon the progress of the work being conducted by his colleagues in adjacent areas. In addition we expect him to be a helpful individual, who will go out of his way and forget his own pursuits at times to help a colleague out of a difficult situation, and all of this occurs. But if a senior investigator believes he has a lead which will take him to far-reaching results along the lines of our general interests, there is nothing in our rules or in our practice to prevent him from pursuing his individual way with full intensity and with the full support of his colleagues in so doing. This is the sort of fundamental pursuit of knowledge which yields momentous results in the long run. It is only necessary to be sure that those who have the extraordinary privilege are worthy of it, and for this we must rely on their reputations among their own peers.

The Institution differs from a university in many ways. For one thing, the staff are not distracted by the manifold duties that are inevitably a part of the operation of a great university. For another, the business organization of the Institution is designed to lift from the shoulders of investigators as far as is physically possible the burdens that sometimes inevitably intrude in an organization having less singleness of purpose.

But there is a third way in which we differ, and this is not so favorable. A professor in a university comes in contact necessarily with young minds. An investigator in an independent research organization can shield himself from such contact quite completely if he wishes to do so, or even unconsciously if he naturally shrinks from the give and take, sometimes roughly pursued, which is inherent in contact with young active minds. There is a distinct danger here, for we depend upon young and vigorous minds to keep us from getting stale, and the scientist who removes himself from direct and almost daily criticism is only too likely to get into a groove, or to cherish some personally constructed and bizarre fashion of thought. There are, however, ways in which we offset our otherwise serious isolation from teaching and from youth generally. Several of our Departments are located adjacent to great research centers in universities. Those in the city of Washington participate closely in the scientific affairs of the Federal Government. We have

summer conferences, our staff members occasionally give courses of lectures on invitation, and there are always the important scientific meetings, national and international, attendance at which is sometimes salutary. But we now have in addition a fellowship program which brings young scientists into our midst on a temporary basis, and also a plan for inviting scientists of standing to be our guests. Neither of these plans is rigid in outline. There are, for example, in connection with our fellowships, no rules which limit selections in accordance with academic status or nationality. In inviting guests we have no formalism to consider, but only the question whether a visit will be genuinely beneficial to the guest and to ourselves and thus to the advancement of science. The fellowship program in particular seems to be working well. We have had an excellent group of younger people and they have performed admirably. The program is still in its formative stages and warrants close attention and reasonable expansion.

RESEARCH ACTIVITIES

In the development of modern science it often happens that the creation of a new tool for research is as important a step in attaining the ultimate goal of new knowledge as the actual use of the tool in a research program. This is especially true in astronomy, since most astronomical investigations deal with extremely distant and faint objects. Without telescopes of great light-gathering power to collect an adequate amount of light, the astronomers would be nearly helpless.

Furthermore, the design and construction of such a tool may require as much ingenuity, effort, and expense as its later use for research. Thus the attainment of the great light-gathering power of a

modern telescope means the design and construction of very large optical parts and of huge moving structural members to support them. Moreover, combined with this size must be the accuracy of form and precision of movement of the finest small laboratory instrument. Because of the great rapidity with which flexure, temperature distortions, and errors of manufacture increase with the size of a structure, this requirement poses problems of the greatest difficulty to the designer.

Once successfully constructed, however, such a telescope provides a basic instrument for all kinds of astronomical research during the decades to follow. The instrument may be used by itself to obtain

direct photographs, or it may be combined with spectrographs or photometers for the study of spectra or the measurement of magnitudes. As new auxiliary instruments are developed during the ensuing years, they may be attached to the telescope to utilize the light it collects, often in ways not originally contemplated when the telescope was built. Thus many of the past "largest" telescopes, constructed thirty, fifty, and even seventy-five years ago, are still active and effective instruments of research today.

The initiation of scientific observations by two notable new instruments, each of outstanding size, was without question the most important research event of the year at the Mount Wilson and Palomar Observatories. The larger of these instruments, the great Hale 200-inch telescope, was first used for taking photographs on a limited observing program during the winter of 1949. Though at the end of the report year some adjustments and minor modifications of this instrument were still necessary before a regular observing program could be scheduled, the earlier trial program provided enough tests to give assurance of the great power of this instrument in attacking many of the outstanding problems of astronomy. Last winter, the Institution, with its friends and collaborators of the California Institute of Technology, had in the Hale telescope a masterful instrument, perfect for average seeing conditions. Powerful as it then was, it was not enough, and the delicate task of further polishing, further refinement, was undertaken. Now, the great instrument is ready, not merely for average seeing conditions, but for those rare occasions when seeing conditions are extraordinary.

The smaller of the new instruments, the 48-inch schmidt camera, was given its

test exposures in the fall of 1948 and was placed in regular service in the following winter. Like the Hale telescope, this instrument is the largest of its type that has thus far been constructed. The schmidt camera is a new development of the past two decades. Because of its ability to give almost perfect definition over a very large plate (14 by 14 inches in the present instrument), it is largely displacing lens-type cameras for survey purposes. The present instrument has fully come up to expectations from both the optical and the mechanical standpoints. These two instruments will make a most powerful asset for astronomical research, the smaller one to find, the larger one to study in detail new objects in the universe about us.

The rare stars with peculiar properties are an object of search by astronomers, since study of them may give important clues to understanding of stellar atmospheres. A thirty-year hunt for several types of these rare objects, including emission-type B stars, planetary nebulae, and T Tauri stars, all of them characterized by bright hydrogen lines, was completed during the year, Dr. Bowen reports. It was a highly successful search. Some 1400 emission line stars, mostly of class B—a many-fold increase in the number of known objects of this type—have been detected in the photographic plates resulting from the study. About 200 new planetary nebulae, more than doubling the observed number of these objects, have been found. In this search, characteristic of astronomy in its patient duration, a 10-inch wide-angle camera with an objective prism and red-corrected lens made it possible to work with the red part of the spectrum, where the strongest of the hydrogen lines is located. This survey of the northern sky having been completed, the search will now turn to the southern sky. The camera

and its mounting have been loaned to the University of Michigan for a similar survey from the University's station in South Africa.

The investigations at the Geophysical Laboratory are now focused sharply on the formation and properties of rock-forming minerals with and without the presence of mineralizers, such as water, for the general purpose of understanding the complex processes by which the earth was formed. Of the many thousands of minerals that are known to the geologist, only a dozen or so are of any great consequence in the genesis of rocks; and in this limited class two, quartz and feldspar, occupy a pre-eminent position. The Laboratory, which in its earliest days logically gave primary attention to these particular minerals, has now with vastly improved apparatus and techniques turned again to the study of some of their characteristics. Quartz has the interesting property of changing at 573°C. from one crystalline form to another. Recent measurements have shown that the transformation temperature is not a fixed point as it was formerly believed to be, but may vary by nearly 2° , which even at moderately high temperatures is an interval that is readily measurable with modern precision thermometric devices. It appears that the variation in the behavior of different quartz specimens is related to the conditions under which the quartz originally crystallized; and, therefore, that a further correlation of inversion temperature with geologic environment will furnish a valuable clue to the temperature of formation of any given sample of quartz.

Related information has been provided by the measurements on feldspars, which consist mainly of three different types depending on the predominance of lime, soda, or potash. In the work on hydro-

thermal synthesis, it has been discovered that the sodic form, albite, may exist in either of two different modifications depending on the temperature of formation. Natural albite is usually of the low-temperature form, whereas that produced synthetically hitherto has always been of the high-temperature variety. Other peculiarities in feldspars are understandable through the discovery that the solid solutions existing at elevated temperatures sometimes unmix at low temperatures, the extent of unmixing depending on the temperature. An X-ray technique permits ready determination of the composition of many feldspars. Further work is needed, yet already the new method of study appears to make it possible to determine the temperature of formation of feldspar when any two feldspars are found together in a single place. Thus there is now a strong likelihood that both quartz and feldspar will provide reliable geologic thermometers by which the temperature of past earth processes may be inferred.

The Department of Terrestrial Magnetism has brought to successful conclusion a series of experiments focused on one of the few direct and clear-cut puzzles in geophysics, that of the maintenance of the earth's electric charge. Since the voyages of the *Carnegie* during World War I, it has been known that the earth always carries a rather large negative electric charge, shown by the electric field near the surface in fair-weather areas over land and sea. This charge is maintained despite a measured total air-earth current, summed up for all fair-weather areas, of 1500 amperes, flowing in the direction which tends to dissipate the charge. The suggestion was made in England more than twenty years ago that thunderstorms might supply the necessary reverse current, but it has never been possible to prove or

reject this idea because of the tremendous variability of the air-earth currents observed beneath thunderstorms.

At the end of 1946 the Department requested the U. S. Air Forces to collaborate in an effort to resolve this problem by making appropriate measurements in the clear air above a thunderstorm. The experiments were undertaken and during the past two years have necessitated many hours of flight, often at record heights. The resulting measurements have shown that the electric current between the upper atmosphere and the ground, in localized areas above active thunderheads, is reversed in sign to the fair-weather current and greatly increased in intensity. The activity observed over a typical storm area, resulting in a net current from the solid earth upward to the ionosphere, multiplied by the average number of storms in progress over the whole earth at any one time, is just enough to counterbalance the 1500-ampere current to the earth which was found for the total of all fair-weather areas.

When the staff of the Department of Terrestrial Magnetism resurveyed the status of knowledge of "the electric and magnetic condition of the earth and its atmosphere" in 1946, three conspicuous puzzles were selected as basic problems of primary significance, disregarding the point that each of these seemed at the time largely inaccessible to direct investigation: (a) What are the direct and indirect causes, inside the earth, of the main part of the earth's magnetic field? (b) What mechanism supports and maintains the earth's net electric charge? (c) What and where are the origins of cosmic-ray particles? One of these underlying problems, that of the earth's electric charge, is now resolved with reasonable clarity, and important information on a second

one, the origin of cosmic rays, was unexpectedly provided by the Department's observations, reported two years ago, of sudden cosmic-ray increases accompanying solar flares and radio fade-outs. Since, in general, direct contributions toward the solution of fundamental puzzles, even when the basic questions are recognized and conspicuous, are the exception and not the rule in scientific work, these unexpected successes further encourage a policy which deliberately focuses attention on the formulation and attacking of basic problems even when they seem inaccessible.

For years discussion has been aroused by the theory that the continents of the earth as we know them may have drifted from some earlier configuration to their present pattern, and, indeed, that they may still be imperceptibly moving. Studies of the direction of magnetization of rocks laid down in early epochs now show some promise of yielding evidence bearing on this question. There are rocks in the Blue Ridge Mountains near Washington which are magnetized as though they had originally been laid down in South Africa. Possible instability of magnetic north and possible large-scale local magnetic disturbances from electric current systems inside the molten earth will have to be reckoned with in any effort to explain why this is so. That effort certainly will also have to consider the hypothesis that the crust has moved with respect to geographic north since the ancient epoch when these rocks were laid down.

Studies by the Department on prehistoric changes in the direction of the earth's magnetic field—the compass direction—hitherto made at specific locations in New England and under the Pacific Ocean, by determinations of the residual magnetization of samples of clay and unconsolidated sediments, were extended this year back

into geological periods earlier than two hundred million years ago. This was done by making observations on a long series of sedimentary rocks. The unfolding of this story of ancient magnetism in recent years at the Department has been dramatic as it progressed, first in painstaking fashion back through twenty thousand years of the last glacial period, then leaping back one million years by measurements on ocean cores. This encouraged an expedition to the west, carrying the record back through eighty million years by measurements on rock samples collected in the region extending from South Dakota through many parts of the Rocky Mountains to the Cascades. This year the story rolls time back more than two hundred million years to a period prior to the folding of the Appalachian Mountains, by studies of sandstones found in Maryland and Virginia which were laid down more than three hundred and fifty million years ago. Studies of the direction of residual magnetization of rock samples taken from different portions of a fold show that the magnetic vectors in the different samples would be parallel if the folded rock were returned to its original flat condition. These "reconstructed compass directions" are found parallel to each other for locations 50 miles apart amid the folded rocks, although the vector found differs violently from the present compass direction. The complex magnetic pattern found in the folded rocks could not be produced by any possible ancient system of localized earth currents, but the parallel vectors in the original flat rocks might well be a record of the compass direction when the rocks were laid down in that ancient Silurian epoch, just as the varved clays of New England show the compass direction of twelve thousand years ago, and clay suspensions redeposited

in the laboratory show the 1949 compass direction in Washington.

Any conclusions on the problems suggested by the findings thus far made in this study will be unjustified until they are supported by long and comprehensive studies of similar and related rocks from widely distributed sites. In support of the initial series of exploratory observations required for this purpose, the Carnegie Corporation has made a special grant to the Institution, and field studies have been started at a series of locations from Alabama to Maine.

It was hardly anticipated that studies of the prehistory of the earth's magnetic field, in search of causes internal to the earth which could produce that field, would lead to these startling questions relating to motions in the earth during early Paleozoic time. It is reasonable to expect that a highly complex but interesting picture eventually will be found in the magnetic pattern of these ancient rocks. It is reasonable also to expect this magnetic pattern in part to be related to "secular variation foci" which we believe are caused today by electric currents deep inside the earth. These special effects may have been much greater in those ancient periods when the earth was younger and presumably more fluid. In any event it will be interesting to follow the further development of these studies of such a delicate and intangible phenomenon as the compass direction and its variations, through one age after another during the long sweep of geologic time.

Steadily increasing pressure of population the world over confronts us with the need for new sources of food. Great changes are surely to be foreseen in the ways by which mankind is fed; some of them will involve new syntheses; others will be simply the improvement and elabo-

ration of customary methods. One promising possibility is that lower organisms such as yeasts and algae can become sources of the protein and the fats that we must have. Studies of the green alga *Chlorella* which have been proceeding for some years past at the Division of Plant Biology give us a gauge of possibilities. Under controlled conditions, with generous supply of carbon dioxide, *Chlorella* cultures constitute a plant growth that doubles itself every day and that can be made to yield more heavily of protein or of fat by suitable changes in growing conditions. The proteins produced by these cultures contain all the amino acids commonly associated with nutrition. The program has shown the desirability of investigation of the practicability of producing *Chlorella* on a large scale for the possible production of foodstuffs. Much remains to be learned, of course, and the problem becomes primarily one of engineering. The Institution hence has entered into arrangements with Research Corporation providing for support to the Stanford Research Institute in an intensive investigation of the process and products on a pre-pilot plant scale. The Institution will co-operate in the undertaking.

The process of photosynthesis, by which green plants transform water and carbon dioxide into the foodstuffs on which we depend, is a primary focus of the Division's program. The first step in photosynthesis is the splitting of water molecules by the action of light absorbed by the chloroplast pigments in the plant. This has been investigated during the year in colloidal solutions of chloroplast material. In such preparations obtained by ejection of chloroplast suspensions through a needle valve under high pressure, Dr. French reports, the activity has been found to be greatly increased by the aggregation of

the colloidal particles on addition of salt solutions in the presence of dilute methyl alcohol.

From measurements of the effectiveness of different wave lengths of light on corn and bean seedlings which have been grown in darkness, it was found that only the light which is absorbed by protochlorophyll, and not that absorbed by any other pigments present, can lead to chlorophyll formation.

To further the development of improved range grasses with the ultimate aim of better pasturage for food animals, co-operative experiments on forty-six strains of range-grass hybrids have been arranged by the Division of Plant Biology with a number of widely scattered laboratories. This has been done to test the climatic adaptability of *Poa* hybrids over a wide range of climatic conditions such as are found in the state of Washington, in southern California, North Carolina, Scotland, Wales, Holland, Denmark, Norway, Sweden, and Transjordan. Fortunately, many of these improved strains breed true from seed, and thus are easy to distribute. Some of these grass hybrids of particular interest have been selected for use in a quantitative experiment on their growth response in controlled laboratory environments.

At the Department of Embryology the collection, preparation, and study of human embryos proceeded successfully during the year. A human egg in the 2-cell stage and a blastocyst of about $4\frac{1}{2}$ days were added to the collection by Dr. Arthur T. Hertig, Research Associate, and Dr. John Rock, collaborator. These are stages of normal development never previously seen. At about the time of implantation the human embryo differs from those of other mammals in certain peculiar characteristics. It is therefore of interest that

these two specimens, earlier than the implantation stage, closely resemble the embryos of other mammals of comparable age. About a dozen valuable human embryos of later stages were serially sectioned by Dr. Heuser for addition to the Carnegie Collection. The collection of specimens bearing on the problem of defective development was augmented by five embryos and fetuses that had been aborted by physicians because the mothers had German measles in early pregnancy. Such defects as these specimens may prove to have will no doubt throw light on the embryological nature of the damage done in such circumstances, which so often leads to blindness, deafness, and mental retardation of the infant.

Dr. J. R. Schlegel, guest of the laboratory on a Rockefeller Fellowship, developed a promising method for determining the time of passage of solutes from the blood vessels to the lymphatic collecting vessels. The method depends upon the use of a dyestuff which is highly specific for the endothelial lining cells of vessels. Being fluorescent, it is readily detectable in ultraviolet light.

Among the important publications of the year was a monograph in the Contributions to Embryology of the Carnegie Institution on the blood vessels of the uterus and particularly of its lining membrane in pregnancy and of the placenta, representing many years of work by Dr. Elizabeth M. Ramsey. Dr. S. R. M. Reynolds and a group of collaborators brought out a series of papers dealing with the physical form of the uterus as it changes during pregnancy to accommodate the fetus, with the adaptation of the uterine blood vessels to pregnancy, and with the physiology of the uterus during labor.

Dr. Louis B. Flexner and his associates,

including Dr. Dean B. Cowie of the Department of Terrestrial Magnetism, made an important contribution to the question of the permeability of blood capillaries, showing that the whole of the capillary wall, not merely the intercellular cement substance, as some have thought, is available as the path for the diffusion of electrolytes from the blood into the tissues outside the capillaries. A striking finding from these studies is that the rate of passage of water through the capillary walls is very high. An amount of water equal to a man's entire weight passes out of his blood capillaries, and is replaced by an approximately equal amount, every 20 minutes.

At the Department of Genetics, additional experimental evidence has been obtained that the unit of heredity, a gene locus, may control several reactions, some of which may have several biological effects. Working with maize, Dr. McClintock by a special technique is able to bring an unstable gene into proximity with a stable gene locus and is thus enabled to analyze more fully the composition and action of the normal locus. One of the normal loci studied is shown by this analysis to be compound, in that it accounts for at least two reactions associated with the appearance of a single end product.

Dr. Demerec's studies of the resistance of bacteria to antibiotics such as streptomycin give another kind of evidence of the great complexity of the gene locus. What appears to be a single gene locus, it is indicated, controls a series of reactions. One change in this locus gives a mutant which is resistant to streptomycin; another change in the same locus produces a mutant which must have streptomycin in order to survive; still other changes produce still other mutants. The im-

portance of this locus may be great indeed. If "nature strikes back" with bacteria which withstand the antibiotics developed by man as a defense against disease, nature apparently strikes back in one of its reactions to our interference by subtle changes in this minute spot. Different changes here control reactions giving biologically different end results. A study of reverse changes in this locus indicates that they are probably not brought about through a reversal of the original chemical reaction, but through some other change in the same gene locus.

Cancer, on which the massed attack of many sciences is leveled throughout the nation, is an elusive foe. We know little about its basic origins. It takes many forms. One of these is leukemia, the condition due to disarrangement of the blood-making organs which results in the formation of an excess of white cells in the blood. Leukemia in mice has been under study for years by Dr. MacDowell at the Department of Genetics, and he continues progress toward elucidation of the problem. During the report year, for example, his investigations have indicated that among mice the resistance to leukemia previously noted in the offspring of older mothers as compared with the offspring of younger mothers is closely paralleled when the offspring of young mothers are fed by older nurses. It thus appears that in mice the age of the nurse has as certain an influence after birth upon the incidence of spontaneous leukemia and upon length of life as has the age of the mother before birth.

The rodlike bodies called chromosomes in the nucleus of the cell are of extreme importance because of the fact that they are the carriers of genes, the units of heredity. Nearly infinitesimal—typically about seven millionths of an inch in diam-

eter—the chromosome threads are truly the network of vital inheritance. Naturally they are a center of scientific interest. Cytochemical studies at the Department of Genetics by Drs. Kaufmann and McDonald continuing during the year past have utilized purified enzymes in the effort to explain the organization of the chromosome. Successive treatments with nucleases and proteases are used by the investigators to dissect the chromosome. The investigation indicates that structurally the chromosome is an integrated fabric whose proteins constitute an interrelated system and whose nucleic acids are closely linked with the proteins and perhaps with one another. No single protein or nucleic acid, it appears, may be considered the basic structural component of the chromosome.

Studies of the prehistory of Middle America have recently been developing the fact that the early pre-Classic cultures of those regions were much more advanced than once had been thought. This knowledge is important in providing a proper understanding of the amazing burst of civilization that occurred in the succeeding Classic Period, a cultural advance that at one time had seemed almost autogenic in its suddenness and its apparent lack of capable ancestry. The Division of Historical Research has taken a leading part in the study of these early cultural horizons. The work of Mr. Shook has shown that the pre-Classic, sometimes called Archaic, cultures which existed in the Guatemala highlands about the beginning of the Christian era present a considerably more complex picture than had been suspected. Rather than a single cultural phase, it is clearly demonstrated, there were at least three sequent phases. Social organization already was developing the ceremonial and hierarchic, probably theocratic, pattern that was to become so char-

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acteristic of the Classic Period. Technology no longer was primitive. These people had a generous background of accomplishment. The primitive beginnings, the proto-pottery cultures, continue to elude discovery; and so long as that condition exists, one cannot disregard the possibility of distant and very early inter-American, or even trans-Pacific, influences.

Other progress of note was made in the solution of problems concerning the lowland Maya area. Dr. G. W. Brainerd's work in eastern Campeche gives promise of solving, or in part solving, a question of chronology that long has been a bone of contention. Although materials collected are still in process of analysis, it is

believed that relative chronology can be established for the previously undated Chenes-Rio Bec remains of Campeche and Puuc remains of Yucatan. Preliminary results suggest that the Campeche ruins are of Late Classic period, and that the Puuc remains are slightly later but in part Late Classic. This cross-dating by means of pottery will place the ruins of two important archaeological areas within the general framework of the native Maya calendar and should add to the understanding of other areas and later periods in Yucatan. In addition to its bearing on chronology, Dr. Brainerd's work has interesting possibilities relative to cultural contacts and influences between areas.

STAFF

It is a pleasure to report that distinguished recognition has come during the past year from various sources to members of the Institution's staff for their contributions to the advancement of knowledge, and to refer specifically to several among the many instances. The Commander's Cross of the Royal Order of Saint Olav was conferred by the King of Norway on September 7, 1948, on Dr. John A. Fleming, retired Director of the Department of Terrestrial Magnetism and now adviser to the Institution on international scientific relations. To Dr. George W. Morey, physical chemist of the Geophysical Laboratory, on November 12, 1948, was awarded the first Arthur L. Day Medal of the Geological Society of America. The medal, named in honor of Dr. Day, retired Director of the Geophysical Laboratory, came to Dr. Morey in recognition of his achievements in the

application of physics and chemistry to the solution of geological problems.

Dr. Ira S. Bowen, Director of the Mount Wilson and Palomar Observatories, is the recipient for 1949 of the Rumford Premium of the American Academy of Arts and Sciences. In the words of the citation, Dr. Bowen is thus honored "for his many contributions in physics and astrophysics, . . . including . . . the development of numerous devices for testing the 200-inch Palomar reflector, which is under his personal charge in these critical days of installation." The Cyrus B. Comstock Prize of the National Academy of Sciences for 1948 was awarded April 26, 1949, to Dr. Merle A. Tuve, Director of the Department of Terrestrial Magnetism, for his accomplishments ranging from pioneering work in the study of the upper atmosphere and in fields of nuclear physics to the development of the proximity fuze.

FINANCES

June 30, 1949 marked the close of the first complete fiscal year since the Institu-

tion's fiscal closing was changed from October 31 to June 30 by amendment of

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the By-Laws on December 12, 1947. During the fiscal year just ended, income available for operating purposes was substantially greater, approximately \$200,000, than for comparable periods ending in 1947 and 1948. This increase in income came about partly from increased investments in common stocks and partly from higher dividend declarations. The increase was anticipated to a certain extent and was taken into consideration in the preparation of the budget for the calendar year 1949, with the result that it was possible to increase the amount budgeted for 1949 substantially over the preceding year. This action has permitted allocation of

funds for projects which had been held under restraint because of lack of funds, and also made it possible to make some adjustments in staff salaries to bring the salary scale to a level comparable with those of leading educational and research agencies.

At the close of the fiscal period a year ago, it was necessary to transfer a moderate sum from reserves to supplement income collections for that period; it is now possible to report that at the close of the past fiscal year we were able to credit reserves with an amount in excess of the sum transferred a year ago.

FREDERIC C. WALCOTT

The death, on April 27, 1949, of Fred-
eric C. Walcott, former Senator from
Connecticut, took from the Institution a
counselor of wide experience in affairs,
long and thorough knowledge of the In-
stitution's activities, and generous interest
in its well-being. A member of the Board
of Trustees since 1931, Senator Walcott
served as a member of the Executive Com-
mittee of the Trustees from 1932 until his
resignation in 1948. Manufacturer, banker,
conservationist, and humanitarian, Sena-

tor Walcott did distinguished work in
association with Herbert Hoover in relief
efforts and food administration during
the First World War. In the Senate of
the United States he served as a member
of the Committee on Banking, and was
the principal author of the bill creating
the Reconstruction Finance Corporation.
He drew unsparingly on this wealth of
experience in his association with the
Institution, and we miss him greatly as a
valued counselor and a loyal friend.

JAMES FORRESTAL

One of the most tragic casualties of the
Second World War was the death, on
May 22, 1949, of James Forrestal, first
Secretary of Defense of the nation which
he had served with devotion. Of his

selflessness, his dedication to duty, no
additional word is needed. It was a matter
of profound gratitude to the Institution
that he had accepted election to the Board
of Trustees in 1948.

REPORTS OF DEPARTMENTAL ACTIVITIES AND CO-OPERATIVE STUDIES

ASTRONOMY

Mount Wilson and Palomar Observatories

TERRESTRIAL SCIENCES

Geophysical Laboratory

Department of Terrestrial Magnetism

Special Projects

BIOLOGICAL SCIENCES

Division of Plant Biology

Department of Embryology

Department of Genetics

HISTORICAL RESEARCH

Division of Historical Research

Special Projects

MOUNT WILSON AND PALOMAR OBSERVATORIES

OPERATED BY THE CARNEGIE INSTITUTION OF WASHINGTON
AND THE CALIFORNIA INSTITUTE OF TECHNOLOGY

Pasadena, California

IRA S. BOWEN, *Director*

OBSERVATORY COMMITTEE

IRA S. BOWEN, *Chairman*
WALTER S. ADAMS
ROBERT BACHER

EDWIN P. HUBBLE
MAX MASON
H. P. ROBERTSON

The current year was marked by the first actual use for scientific observations of both the 200-inch Hale telescope and the 48-inch schmidt camera. During much of the year extensive tests and adjustments of both instruments have been in progress. Though most of the features of these telescopes have performed remarkably well, some modifications, particularly of the 200-inch instrument, have been found necessary to attain the perfection of operation and performance that has been the continual aim in the design and construction.

Since the inception of the 200-inch project, it has been realized that the key to the success of the telescope lies in maintaining the exact optical shape of a mirror of this size in all orientations and often with rapidly changing temperatures. Thus, a simple dimensional analysis shows that the flexure of such a mirror under its own weight is proportional to the fourth power of the diameter of the mirror and inversely proportional to the square of its thickness. Obviously, if the standard astronomical practice of using a fixed ratio of mirror diameter to thickness (usually 8:1) is followed, the flexure under gravitational forces increases as the square of the aperture of the telescope. Because of the difficulties of carrying even the weight of such an 8 to 1 mirror on a moving telescope, it is impracticable to decrease this ratio of diameter to thickness appreciably. In order

to obtain the greatest possible stiffness within the weight limitations, a ribbed structure was adopted for the 200-inch mirror rather than the conventional solid disk. Nevertheless, actual measurements show that with a simple three-point support similar to that which is customary for very small mirrors the flexure would be 500 to 1000 times as great as the permissible value of a very few millionths of an inch.

Obviously, if distortion is to be eliminated as the telescope moves into various orientations, the support system for the mirror must be much more elaborate and precise than any hitherto devised. For this reason the mirror is supported at thirty-six points by units designed to balance the force of gravity on the section of the mirror assigned to each support by applying the correct components of force in all directions. As the orientation of the mirror changes, each of these force components must vary in such a way as to compensate the force of gravity with an accuracy of at least 0.1 to 0.2 per cent.

Similarly, distortions of a mirror caused by temperature changes incidental to actual operation increase rapidly with the dimensions of the mirror. Every effort was made to reduce these distortions by having the mirror cast of Pyrex glass, which has a coefficient of expansion only one-third as large as that of the glass used in most of the earlier astronomical mirrors. Further-

more, the ribbed structure of the 200-inch mirror has a marked advantage over a solid disk in this regard, since the rate at which thermal equilibrium is reached varies inversely as the square of the thickness of the glass. The maximum thickness of the ribs of the 200-inch is 4 inches, whereas a solid disk would have been 20 or more inches thick. Even with these advantages, thermal distortion is a serious problem for a mirror of this size, and every precaution must be taken to insure an equal flow of heat to all parts of the mirror.

Every effort was made to solve these problems by designing the mechanical parts properly; nevertheless, it has been realized that extensive tests and experiments would be required with the instrument itself before all factors could be adjusted to give optimum performance.

Last year's report outlined the results of the early tests of the mirror support system. These indicated that the friction in the original support system was so great that it would be practically impossible for the system to exert the correct supporting forces with the high precision necessary. During the summer of 1948 the lower part of each support unit was replaced with a new part especially designed to reduce the friction. Further tests of the mirror in October and November 1948 indicated a satisfactory reduction in the vertical friction from 1.3 per cent to 0.12 per cent.

During this same period studies were made of the behavior of the outer edge of the mirror as the zenith distance of the telescope was varied. This outer edge of the mirror overhangs the last row of supports from 10 to 20 inches, and concern had been felt as to the amount that this edge might droop when the mirror axis was changed from the horizontal position, in which all laboratory tests in Pasadena had been made, to the vertical. Contrary

to expectations in the early tests, this outer edge turned up more when the telescope was pointed near the zenith than when pointed near the horizon. Further studies, however, indicated that this change was accompanied by a shortening of the focus of the 200-inch mirror as the zenith distance was increased. By a careful analysis it was possible to show that the decrease in the amount of upturn of the edge with increasing zenith distance was a secondary effect on the ribbed structure of changing focal length. Furthermore, when the change of focal length was eliminated by an appropriate adjustment of the support system, the edge drooped as the telescope approached the zenith, but by an amount which did not cause a sensible deterioration of the image formed by the mirror.

After these problems had been solved, extensive tests were carried out to determine the effect on the mirror of sudden changes in temperature similar to changes that are occasionally encountered in actual observing. From these tests it was at once evident that the outer edge of the mirror was changing in response to a new temperature more rapidly than the central part of the back of the mirror. Thus when a sudden drop in temperature occurred, the edge contracted more rapidly than the back central zone of the mirror, with the result that the outer zones of the mirror were pulled back from their proper position by as much as 20 to 40 millionths of an inch. With rising temperatures the opposite effect occurred and the edge was raised. To speed up the changes in the back central zone, twelve fans were installed in the cell underneath the mirror in February 1949. These have partially corrected the situation, and it is anticipated that still further correction can be attained by properly insulating the outer edge of the mirror.

All tests of the 200-inch mirror, including those made in Pasadena prior to its transportation to the mountain, indicated that its outer edge was too high by amounts ranging up to 20 millionths of an inch. Because of the uncertainty as to how much this edge might droop when the telescope was placed in a vertical position, it was considered inadvisable to correct this outer zone until the mirror could be thoroughly studied in all orientations. This was particularly true since a turned-down edge, which would result if the correction were carried too far, would be much more difficult to rectify than a turned-up edge.

With the completion of the studies and modifications outlined above, it became possible to proceed with confidence with the removal of the proper amount of glass to correct this outer zone. The mirror was taken from the telescope in May 1949 and its original coat of aluminum removed. Polishing off the high zones was started in June with simple equipment designed for local figuring. The polishing is carried out on the observing floor of the dome with the mirror resting on the base of the aluminizing tank. After the removal of as much glass as seems advisable, the mirror is replaced in the telescope and tests of the figure are made using a star as a source. As might be expected, the survey of the whole surface of the mirror with the necessary accuracy of a very few millionths of an inch after each period of polishing is a much more time-consuming operation than the polishing itself.

Two types of tests are made. The first of these is the standard knife-edge test, which provides a qualitative survey of the deviations from a true paraboloid at all points of the surface. To provide a permanent record of the shape of the mirror at each stage of this final figuring process, a large number of photographs are taken of the knife-edge patterns. In general, eight

different angles of approach of the knife edge are studied, and at least four photographs representing different positions of the knife edge are taken for each direction of approach. The second type of test consists in quantitative surveys along twenty diameters across the mirror, made with a full-sized Hartmann screen having twenty holes per diameter.

Because of the closing of the California Institute Optical Shop, Dr. Anderson and Mr. Brown, who had so ably carried out the original grinding and figuring of the mirror, were not available for these final corrections. Mr. Hendrix, of the Mount Wilson Optical Shop, has therefore been in charge of this figuring.

Early in 1949 it seemed desirable to obtain checks on the results of the Hartmann and other tests of the mirror from a study of the performance of the telescope when in actual operation on a limited astronomical program. Consequently, during gaps in the testing program the telescope was used for a moderately extensive series of test photographs with apertures of 140 to 200 inches. Although confirming the fact that the outer 15 or 20 inches of the mirror were only partially effective, these photographs were on the whole remarkably successful. Many objects were clearly recorded that are well beyond the range of any other telescope. In fact, the theoretical gain over previous instruments was so nearly reached that there is every reason to believe that after the correction of the outer zone the telescope will fully come up to all expectations.

The optical parts of the 48-inch schmidt camera, including the very difficult non-spherical correcting plate, were completed by Mr. Hendrix, of the Mount Wilson Optical Shop, in the summer of 1948 and were installed in September of that year. After the usual adjustments and minor

modifications were made, the instrument was placed on a regular schedule of observations in January 1949.

The performance of this instrument has been remarkably fine and has in every way come up to the specifications for it. This camera normally uses plates 14 by 14 inches and therefore photographs about 40 square degrees of the sky at one exposure. The definition of the optical system is so superb that at all parts of this large plate the definition is limited by the resolving power of the photographic emulsion rather than by the optical system. Early tests have shown that a limiting magnitude of 20.3 is regularly reached. The mechanical and electrical parts of the telescope have likewise performed very satisfactorily.

In June 1949 announcement was made of an agreement providing for joint support by the National Geographic Society and the California Institute of Technology of a project for mapping, with the 48-inch schmidt camera, the whole sky visible from the Palomar Observatory. Each section of the sky will be photographed once in red light and once in blue light. Since approximately 1000 plates in each color will be required to cover the sky, it is anticipated that a period of four years will be necessary to complete the survey. This survey makes it possible for the first time to map the whole sky to a depth and in detail comparable with that reached by the large reflectors. In several decades of operation, these large reflectors with their limited fields have covered only one or two per cent of the sky; hence it is anticipated that complete coverage with the new schmidt camera will bring to light a great wealth of objects. These objects will provide material for detailed study with the 200-inch and 100-inch telescopes and with the large instruments of other observatories. In addition, the survey plates will

themselves provide important material for statistical studies of the distribution of many types of faint objects.

During the year rapid progress has been made in the design and construction of auxiliary equipment for the 200-inch Hale telescope. The base frame and many of the mountings for mirrors, plateholders, and gratings of the large coudé spectrograph have been installed. This spectrograph will use a four-unit composite grating, designed to accommodate a beam from the collimator 12 inches in diameter. Schmidt cameras having focal lengths of 18, 36, 72, and 144 inches and giving dispersions of 18, 9, 4.6, and 2.3 angstroms per millimeter are to be provided.

As the construction period of the Palomar project has drawn to a close, extensive reorganization of the shops built for this project has been carried out. Since in the future only a small fraction of the capacity of the machine shop on the campus of the California Institute will be required for Observatory operations, it has been reorganized as a central machine shop for the use of all departments of the Institute. Though much of the Observatory construction will continue to be done at this shop, the reorganization will substantially decrease the fraction of the shop overhead to be carried by the Observatories. The optical shop ceased operations on May 1, 1949, with the completion of the last of the major optical parts for the Hale telescope. All future optical construction of the Mount Wilson and Palomar Observatories will be carried on at the Santa Barbara Street shop under the supervision of Mr. Don Hendrix. Mr. Melvin Johnson, of the California Institute shop, has been transferred to Santa Barbara Street to augment the original staff.

During the present year the location of the 200-inch dome has been determined

by the United States Geological Survey as follows:

Latitude: 33 degrees, 21 minutes, 22.41
seconds north
Longitude: 116 degrees, 51 minutes, 50.38
seconds west
or 7 hours, 47 minutes, 27.359
seconds

The elevation of the observing floor of the 200-inch dome is 5598.5 feet above sea level.

For the past several years reports have been given of the progress of a search for planetary nebulae and early-type stars with emission lines, with a camera having a 10-inch red-corrected lens of the triplet type. This survey has now been completed for all parts of the Milky Way visible from Mount Wilson. During the present year this camera with its mounting and drive was loaned to the University of Michigan, which has transferred it to the Lamont-Hussey station at Bloemfontein, South Africa. At this station Mr. Karl Henize, of the University of Michigan, will use the instrument to complete the survey of planetary nebulae and emission-line stars in the southern part of the Milky Way that is invisible from northern latitudes.

Current investigations at the Mount Wilson and Palomar Observatories are continuing along the lines of the two broad programs that have characterized much of the work of the Mount Wilson Observatory for the past quarter century.

The first of these programs includes a series of investigations planned to extend our knowledge of the large-scale structures of the universe. Studies are first made of the distances, spatial arrangements, and motions of the stars in our own Milky Way system. Already it has been shown that this system is a huge disklike structure some 100,000 light-years in diameter, containing billions of stars and rotating

slowly about a central axis perpendicular to its plane. Similar investigations are then made of the structures, dimensions, distances, and internal motions of the nearer of the extragalactic nebulae, which are now known to be other stellar systems of the same general size and type as our own Milky Way system.

Finally, in another series of studies the spatial distribution and the motions of the more distant of these extragalactic nebulae are investigated. These latter studies are extended out to the greatest distance at which these huge systems can be photographed, and are concerned with such problems as whether the nebulae are uniformly distributed throughout observable space or whether a boundary is finally reached beyond which no further objects are found, thereby indicating a limit to occupied space. Earlier studies of the motions of these nebulae produced the result that all these objects appear to be receding with velocities proportional to their distances. This led to the concept of an expanding universe. The true significance of this phenomenon, however, awaits further velocity measurements on still more distant nebulae.

For the Hale telescope it is estimated that the limiting distance to which these investigations can be carried is one billion light-years, or twice as great as that reached by any previous instrument. In other words, this instrument will extend the boundaries of the observable universe to include a volume of space eight times as large as could previously be reached. Within this volume it is estimated that there are some hundreds of millions of these stellar systems.

Obviously the answers to the most fundamental problems of cosmology, including the structure and extent of the universe, the significance of the expanding universe, the possible curvature of space, and many

other similar problems, depend on further observations in this field. High hopes are held for the effectiveness of the Hale telescope in obtaining the solutions to many of these problems which depend on pushing out to the boundaries of the observable universe.

Much of the information about the structure of the Milky Way and the structure and spatial distribution of the extragalactic nebulae is obtained from a study of direct photographs of these objects taken with the telescopes used as cameras of long focal length and great light-gathering power. With the exception of a few of the closest stars, the distances of the objects are determined from a comparison of the absolute brightness or candle power of the object with its apparent brightness as estimated from a photograph or measured with a photoelectric cell. The facts necessary to assign a star to a given class of known absolute magnitude are found from a study of its spectrum or, if it is a variable star, from a determination of the period and form of its light-variation. Motions of near-by objects across the line of sight are measured by observing the change in position over a period of years; velocities toward or from the observer are readily fixed by a study of the displacement of the lines in the spectrum of the object.

The second program is concerned with the physical and chemical properties of individual stars and other single objects. Since, with the exception of our own sun, all stars appear as points even in the most powerful telescopes, such investigations are limited to a detailed analysis of the star's light by means of spectrographs. In the past century the spectra of all the standard stellar types, as well as those of most of the more unusual types such as variables and novae, have been studied and described with increasing detail as telescopes and spectrographs have become more

powerful. Thus the great light-gathering power of the 100-inch and 200-inch telescopes combined with recent advances in spectrograph design now make it possible to study the spectra of all naked-eye stars in as much detail as was possible for the sun a half century ago. Such spectroscopic studies continue to constitute a substantial part of the observational program of the Observatories.

With the development of theories of atomic structure in the past quarter century, it is rapidly becoming possible to utilize these spectroscopic observations to obtain a more quantitative understanding of stellar characteristics. Thus from measurements of both the positions and the intensities of the lines of a stellar spectrum one may obtain a quantitative chemical analysis of the stellar atmosphere. Similar measurements make it possible to fix the temperature, the pressure, and the strength of the magnetic field in the observable surface layers of the star's atmosphere. Study of the spectrum also throws light on the structure of the star's atmosphere and the circulation of gases in it. With the aid of theory it is possible to extrapolate the temperatures, pressures, and densities to the center of the star and to understand the flow of heat out from the central regions where it is generated.

Recent nuclear experiments and theories point definitely to the hypothesis that the energy which a star radiates in such tremendous quantities comes from nuclear transformations of one chemical element into another. These reactions are of the same general type that gives the atomic bomb its enormous power. Information concerning the central temperature and density of typical stars combined with a knowledge of chemical composition is necessary to determine which of the possible nuclear reactions are most effective in each stellar type. Quantitative determina-

tions of chemical composition also provide information as to the extent to which these nuclear fires have progressed in burning up the available supply of fuel. Eventually such studies may throw light on the origin of the chemical elements.

As new theoretical approaches begin to find solutions to these problems, they almost invariably raise additional problems that must be solved by further observations before the final answers are reached. In particular, recent studies of the types mentioned above are requiring quantitative measurements of the intensities of spectrum lines in addition to the measures of their positions which were provided by earlier observations. The Observatories have recently completed a new direct-intensity microphotometer which will very greatly speed up these quantitative intensity measurements.

Naturally all these spectroscopic studies of stellar atmospheres are checked where possible with detailed observations of surface features of the one star where they can be directly observed, namely, our own sun.

As in all scientific work, these broad programs are built up out of a large number of detailed investigations. It is only as the results of these highly specialized studies, carried out at many institutions, are brought together that the general broad pictures of our universe begin to emerge.

The following sections of this report outline the detailed programs that have been in progress during the current year. As-

tronomy is almost entirely an observational rather than an experimental science. For this reason, any observing program must take into account many factors over which the astronomer has no control. Thus, observations of any given object can be made only during the time of year at which the object is in the sky for a substantial part of the night. Particularly if long exposures are necessary, observations are therefore limited to a period of from two to four months each year. Several years may thus be required to accumulate the necessary observations on a particular object, and parallel studies of other objects must be planned to utilize the remainder of the observing periods during each year. Furthermore, many programs are concerned with changes in the spectra, in the brightness, or in the positions of objects. Many of these changes occur slowly and often may require years to complete a cycle. Again, occasional observations spread over long periods are necessary for these studies.

Because of these conditions it is customary and indeed necessary for effective operation that any given observer have a substantial number of programs in progress at any one time, many of which will require several years for completion. As a result, any record of the projects to which the members of the staff of the Observatories have devoted time in a given year is a long one, much longer than would be normal for a staff of the same size working on experimental problems.

OBSERVING CONDITIONS

The total precipitation for the season of 1948-1949 was 21.63 inches, which is the third lowest on record on Mount Wilson. This dry season following the record low rainfall of the preceding year has had a serious effect on the water supply of the mountain. By the application of moderate

restrictions on the use of water it has been possible, however, to maintain an adequate reserve in the reservoirs, and no serious difficulty is anticipated unless there are additional unusually dry years. The snowfall was 84 inches.

Solar observations were made on 312

days between July 1, 1948 and June 30, 1949. During this period the 60-inch telescope was used on 282 nights, the 100-inch on 263 nights.

SOLAR RESEARCH

SOLAR PHOTOGRAPHY

Solar observations were made by Hickox, Hoge, Nicholson, and Richardson. The numbers of photographs of various kinds were:

Direct photographs	612
<i>Hα</i> spectroheliograms of spot groups, 60-foot focus	972
<i>Hα</i> spectroheliograms, 18-foot focus	1,204
K $_2$ spectroheliograms, 7-foot focus	41,680
K $_2$ spectroheliograms, 18-foot focus	879
K prominences, 18-foot focus	1,098

SUNSPOT ACTIVITY

The magnetic classification and study of sunspots and related phenomena have been continued by Nicholson and Miss Whitney. Co-operative programs have been carried out with the United States Naval Observatory, the Observatory of Kodaikanal, the Department of Terrestrial Magnetism of the Carnegie Institution, and the Central Radio Propagation Laboratory of the National Bureau of Standards.

During the calendar year 1948, observations were made on 334 days, none of which was without spots. The total number of sunspot groups observed was 582, compared with 663 in 1947. The number of groups in the northern hemisphere decreased from 309 in 1947 to 271 in 1948; in the southern hemisphere, from 354 to 311.

The monthly means of the number of groups observed daily during the past two and one-half years are given in the accompanying table.

The number of sunspot groups observed daily has varied in characteristic short-

Month	Daily number		
	1947	1948	1949
January	9.9	10.6	8.7
February	10.5	8.1	13.6
March	11.8	8.0	14.7
April	11.5	14.4	12.1
May	16.8	12.7	10.2
June	13.4	12.2	9.6
July	12.9	11.4	....
August	14.1	12.4	....
September	13.7	10.8	....
October	12.4	10.7	....
November	10.8	9.2	....
December	10.1	10.2	....
Yearly average	12.3	10.9	....

period fluctuations. Three marked maxima have occurred at intervals of 11 months, in May 1947, April 1948, and March 1949, with monthly means, respectively, of 16.8, 14.4, and 14.7 groups per day. The great activity of May 1947 and of the other months of that year marks the middle of 1947 as the maximum of the cycle.

SUNSPOT POLARITIES

Magnetic polarities in each spot group have, so far as possible, been observed at least once. The classification of groups observed between July 1, 1948 and June 30, 1949 is indicated in the table on the next page. "Regular" groups in the northern hemisphere are those in which the preceding spot has S (south-seeking) polarity and the following spot N polarity; in the southern hemisphere the polarities are reversed.

Hemisphere	Regular	Irregular	Unclassified
North.....	226	6	79
South.....	214	4	71
Whole sun....	440	10	150

FLARES

As a result of the discovery of apparent relations between solar flares and such phenomena as radio transmission, terrestrial magnetism, and cosmic rays, there has been a steadily increasing interest in data on flares and the spot groups associated with them. The automatic patrol program was amplified in March 1949 to take five times as many spectroheliograms as before. The photographs are now taken at the rate of one per minute in series of five exposures, each exposure with a different diaphragm over the collimator. These graded exposures serve as an intensity calibration, furnish a much finer time scale, and make the detection of faint flares more certain.

PROMINENCES

The eruptive prominence of June 3, 1949 was photographed by Hickox with the 13-foot spectroheliograph, and variations of its velocity with time were studied by Pettit. The prominence rose to a height of 870,000 km in 12 hours. The time-distance diagram gave successive velocities of 1.5, 7, 33, 85, 137, and 192 km/sec. Of these, the 1.5 and 33 km/sec velocities were very definite. The motion was somewhat erratic during the periods having average velocities of 7 and 192 km/sec and appeared to accelerate slowly during the periods having average velocities of 85 and 137 km/sec.

SOLAR GRANULATIONS

Spectra of the solar granulations have been taken at the center of the solar disk by Martin Schwarzschild, of Princeton University Observatory, and Robert S. Richardson, using the 425-mm image of the sun at the 150-foot tower. Differences in radial velocity are readily apparent from inspection on plates taken with exposures of 10 seconds during periods of fine seeing. Preliminary measures show the hotter material to be rising with respect to the cooler background with a relative velocity of about 0.2 km/sec.

THE H AND K LINES AND MAGNETIC STORMS

Richardson has remeasured the plates taken during the great magnetic storms of September 18, 1941 and March 1, 1942 to obtain improved data for a test of the suggestion by Chapman that a cloud of charged particles moving earthward during a magnetic storm might be detected by a faint absorption line shortward of the solar lines.

The intensities of 48 selected points in the continuous spectrum from $\lambda 3888$ to $\lambda 4007$ were compared on plates taken during magnetic calm and magnetic storm. For the great storm of September 18, 1941, three plates taken a few minutes apart 20 hours 30 minutes after the storm were measured. For the great storm of March 1, 1942, eight plates were measured taken from 15 hours before to 16 hours after the storm. Flares of intensity 3+ were observed about 20 hours before the beginnings of both storms.

Results were obtained in fair agreement with those published in 1944, which were based upon fewer plates and a different method of reduction. For the storm of September 18, 1941, apparent absorption bands dropping 0.06 below the normal

spectrum were observed to the violet of both H and K. For the storm of March 1, 1942, apparent absorption bands dropping 0.03 below normal were observed. The bands indicate a range in velocity of inter-solar ionized calcium of from -600 to -1400 km/sec, although the uncertainties in these velocities are large.

If the absorption bands are real, the effect is barely above the limit of observation by photographic photometry. Even these improved measurements fail to furnish definite observational evidence for the assertion that magnetic storms are due to corpuscular emission from the sun.

GENERAL MAGNETIC FIELD OF THE SUN

Fifteen sets of visual measures of the sun's general magnetic field were made between October 1, 1948 and April 1, 1949 by Nicholson and Hickox using the *Fe* line at 6173 Å. The individual sets gave values ranging from $+43$ to -28 gauss, reduced to the north pole of the sun, with a mean value of -2.3 ± 3.3 gauss. The

probable errors indicate that the range in the measures was accidental and not due to a varying field.

RELATION BETWEEN SOLAR AND TERRESTRIAL PHENOMENA

Nicholson and Dr. Oliver Wulf, of the U. S. Weather Bureau, have extended their studies of the relation of bright solar flocculi to geomagnetic activity, previously reported for 1943 and 1944, to include the years 1941 and 1942. They have compared geomagnetic activity with the declination of the moon over 294 lunar cycles (1925-1946) and have found a tendency for activity to be highest near and following the northerly and southerly maxima of declination, when the lunar air tide is asymmetric with respect to the earth's axis of rotation and to the average air circulation. These and other observations give further evidence that the circulation of the upper atmosphere plays a role in the production of recurrent geomagnetic activity.

STELLAR INVESTIGATIONS

LIGHT-CURVES OF NOVAE

The visual brightness of Nova Puppis 1942 as measured by Pettit with the wedge photometer has now fallen to mag. 11.7. A plot of all the measures since November 10, 1942 on a logarithmic time scale shows a general drop from maximum light with some long-period fluctuations of a few tenths of a magnitude. From Sanford's measures of the distance to the nova and the expansion velocity of the shell it can be estimated that the present diameter of the expanding shell is about $1''.2$. Since the minimum disk detectable under ordinary circumstances is probably about $2''$ in diameter, the shell cannot be expected to be visible before 1952.

The visual brightness of T Coronae Borealis fell gradually from the secondary maximum of mag. 8.0 in the summer of 1946 with some small fluctuations to mag. 9.8 during the year July 1947 to July 1948. It then brightened and is now about mag. 9.6. Slow oscillations of this kind were observed in 1867 at the same interval, 1238 days after primary maximum, and in the same magnitude range. It appears that the light-curve has behaved like the 1866 curve in considerable detail.

SPECTRAL ENERGY-CURVES OF STARS

Pettit has investigated the adaptability of a panchromatic photomultiplier tube to the measurement of spectral energy-curves

of stars. For this purpose the tube in the regular nebular photometer mounting was attached to a Bausch and Lomb quartz monochromator at the Newtonian focus of the 60-inch telescope. Deflections at hundred-angstrom intervals of the spectrum were taken between $\lambda 7000$ and $\lambda 3000$ on α Leonis and ν Virginis. When properly reduced, these measures yielded spectral energy-curves outside the earth's atmosphere.

The energy-curve of ν Virginis, mag. 4.2, type M1, shows a general drop in the visible spectrum and a rapid drop from $\lambda 4500$ to $\lambda 3900$, after which it is about constant at about one-tenth the intensity at $\lambda 5500$. The curve for α Leonis, mag. 1.34, type B8, rises from about one-eighth maximum intensity at $\lambda 6000$ to a maximum at $\lambda 4800$, drops rapidly to about half this value at $\lambda 3700$, then rises throughout the ultraviolet.

STELLAR SPECTROSCOPY

RADIAL VELOCITIES

Completion of the older Observatory radial-velocity programs was delayed, mainly by unfavorable weather conditions during the winter months, when most of the remaining observations must be made. About 65 plates of 53 stars are still needed.

During the report year, 411 plates were taken with the 60-inch telescope on these and the supplementary radial-velocity programs, 319 by R. E. Wilson. In addition, 676 plates were obtained with the 60-inch in connection with special investigations by various observers. Measures of the plates taken on the regular programs are up to date.

Radial velocities have been completed for about 2000 stars. The results together with revised spectral classifications are being prepared for publication by P. E. Wilson and A. H. Joy.

The card file for a general catalogue of radial velocities has been kept up to date; a study has been made of systematic differences between the various observatories engaged in radial-velocity determinations; and the format of the catalogue has been discussed and adopted.

E. R. Dyer, Jr., Carnegie Fellow, who is on a two-year leave from the University of Virginia, is measuring the radial velocities of dwarf M stars selected from objective-

prism plates by Vyssotsky and others at the Leander McCormick Observatory by means of spectrophotometric criteria. It is expected that the inclusion of these stars will give a solution for space velocity less affected by selection than previous material. These stars have visual magnitudes from 8.9 to 11.5 and are distributed over the sky north of -20° declination. From October 1948 to June 1949 slit spectrograms of 110 Å/mm dispersion have been obtained for 148 stars, mostly with the 60-inch reflector, and about half of these have been measured. Eight new stars with Balmer emission have been found, and more than 40 stars with bright H and K lines of Ca II.

The spectral types and radial velocities of 90 dwarf stars of late type which have been under observation for parallax at the McCormick Observatory were published by Joy and Mitchell.

VARIABLE STARS

Spectrograms of 34 of the high-luminosity variable stars of globular clusters were obtained by Joy. By use of the spectral characteristics and the periods it is possible to determine the type of variation of the star. A tabulation indicates that with a few exceptions the cluster variables belong to the RR Lyrae, W Virginis, RV Tauri,

and semiregular (periods 60 to 110 days) classes. The radial velocities yielded by the spectrograms serve to identify the stars with the clusters as well as to help determine the velocities of the clusters.

Forty-four coude spectrograms of cepheid variables and spectroscopic binary stars have been obtained by Sanford for the determination of radial velocities. The spectrum of W Virginis, a cepheid of stellar population II, was found to have double absorption lines for the first couple of days after light-maximum.

Further studies have been made by Sanford of the radial velocities of RR Lyrae from high-dispersion spectrograms. The absorption lines of hydrogen and of H and K were found to become double in each cycle for a short time near median magnitude on the rising branch of the light-curve.

Joy has obtained additional spectrograms of RR Lyrae stars, bringing the number of unpublished stars to 60.

Sanford has continued his investigation of the recurrent nova T Coronae Borealis. Spectrograms obtained in January and February 1949 are essentially similar to the one obtained in May 1948. The study of earlier plates has shown a velocity variation of the lines of the class M spectrum. This variation follows a sine-curve with a semi-amplitude of 21 km/sec and a period of 230.5 days. No velocity variation is shown by the source of the emission lines; hence the assumption that T Coronae Borealis is a binary is beset with difficulty.

Spectrograms of Nova Cygni 1948 were obtained by Sanford, Mowbray, and Joy in June 1948. Emission and absorption lines characteristic of the phases shortly following maximum were present. Velocities of the expanding shells were 560 and 1270 km/sec. A spectrogram obtained on July 1, 1949 showed an advanced nebular stage with weak continuous spectrum and

strong emission lines of H, He II, N III, [Ne III], and [O III].

STARS WITH EMISSION LINES

The Mount Wilson survey of the northern Milky Way for the detection of stars whose spectra have bright hydrogen lines was completed during the past year. This survey, begun by Merrill in 1919, combined the advantage of (1) objective-prism photography with the wide-angle 10-inch telescope with (2) the use of the strong red H α line. Recent photographs have been made with a lens especially designed for red and yellow light; they are far superior to the early plates. Many observers have taken part in the program, the principal ones having been P. W. Merrill, M. L. Humason, W. C. Miller, and A. G. Mowbray. A very large part of the assessment of plates and preparation of catalogues has been done by Miss Cora G. Burwell. The third section of the general catalogue, now ready for printing, brings the number of Be stars to 1088. Of these, about 800 have been detected at Mount Wilson. Awaiting future listing are about 600 additional bright-line objects discovered at Mount Wilson whose spectral types have not been determined; but it is reasonably certain that most of them are of class B.

The spectra of most of the brighter objects discovered in the survey have been photographed again, in more detail, with slit spectrographs attached to the 100-inch or the 60-inch telescope. Several stars have become the subjects of extensive investigation.

Shell stars offer special inducements to detailed study because many of them have extremely active outer atmospheres. About 35 are now known (not counting P Cygni stars or those with combination spectra), of which only a few have been adequately observed. In several stars (HD45910,

187399, 218393) studied during the year by Merrill, the hydrogen lines undergo striking changes in structure and displacement from plate to plate. Of special interest in certain stars is the progression in radial velocity from line to line along the Balmer series. Studies have been continued of the long-period damped oscillations in 48 Librae and in HD33232. In DM-27° 11944 an outflow of gas at the rate of 300 km/sec has continued since 1921. It is hoped eventually to obtain reliable interpretations of the remarkable velocities and accelerations which occur in the extended atmospheres of these objects.

O. C. Wilson has nearly completed the observational part of the spectrographic survey of the northern Wolf-Rayet stars. Three stars with variable displacements presumably due to orbital motion are HD177230 and 197406 and BD+40°4220. Another star, HD50896, shows large variations both in displacement and in shape of some of the emission bands, but it is not yet known whether these effects can be attributed to orbital motion.

An orbit for the Wolf-Rayet binary HD190918 has been completed and published. The velocity variation is relatively small, and if this fact is attributed to small inclination of the orbit, the results show that the observed red shift of $\lambda 4686 \text{ He II}$ in such stars is probably independent of the direction from which they are viewed.

A complete list of the stars whose spectra are known to have H and K (Ca II) in emission was prepared by Jc/ and R. E. Wilson. The intensities of the emission lines were estimated from Mount Wilson spectrograms. Of a total of 445 stars, there are 37 supergiants, 93 giants, 15 subgiants, and 277 dwarfs. Calcium emission evidently occurs frequently among stars of various kinds, but is largely limited to the cooler atmospheres of stars of spectral types later than G5. In the giants and super-

giants the emission lines are divided by an absorption reversal.

ABUNDANCES OF CHEMICAL ELEMENTS

Greenstein is continuing his investigation of abundance, pressure, temperature, and turbulence in stellar atmospheres. Additional studies have been made of F stars, and a detailed comparison of the spectra of giant, subgiant, and dwarf G stars has been started with the highest resolution available. These F and G stars are sufficiently like the sun to provide fairly direct comparisons when detailed studies are made with high dispersion. A preliminary investigation of the subdwarf Groombridge 1830 reveals large differences from a normal dwarf, due to the higher pressure and the higher opacity in the subdwarf.

Two stars with apparent peculiar abundances of certain elements are also under investigation. The carbon-rich, hydrogen-poor star R Coronae Borealis normally shows a metallic-line spectrum remarkably close to that of a late F-type supergiant, the C_2 bands, and a few as yet unidentified features. A detailed program of measurement and identification of the lines in the helium-rich, hydrogen-poor star υ Sagittarii is in progress; high-dispersion spectra are available from $\lambda 3200$ to $\lambda 6600$. In the red, weak emission of Na I , Fe II is observed, besides the strong absorption of Ne I , N I , and the ionized metals. The variation of line intensities around the radial-velocity orbit has been studied by Dr. Adams and found to be small.

GENERAL MAGNETIC FIELD OF EARLY-TYPE STARS

The search for and analysis of stars showing evidence of strong magnetic fields has been continued by H. W. Babcock. Construction and use of a new optical

phase-shifter have permitted effective extension of the observing program to stars north of the equator. This phase-shifter, or compensator, largely overcomes the limitation imposed by the oblique reflection from the coude flat of the 100-inch telescope. One result of this extension is the discovery that the well known bright spectrum variable α^2 Canum Venaticorum has a strong magnetic field, and that the field not only varies, but reverses its apparent polarity in a manner rather similar to that previously found for HD125248. The magnetic variations are very probably synchronous with the 5.5-day period of line-intensity variations. This observation is significant for the interpretation of the spectrum of α^2 Canum Venaticorum, which has been almost intractable heretofore.

Two other stars, HD10783 and HD 153882, have been found to be spectrum variables of type A, and to possess strong magnetic fields that reverse their apparent polarity. Periods have not yet been determined. Considerable evidence on magnetic fields in other stars has been accumulated.

A number of additional spectrograms of HD125248 have been obtained; together with the plates of last year they make a valuable collection, well distributed over the 9-day period of spectral and magnetic variation. Measurement of these plates, with the assistance of Miss Burd, is now well advanced. Tentative results show that elements of the three groups characterized by the rare earths, iron, and chromium are generally consistent among themselves, but that at certain phases systematic differences appear among the three groups in radial velocity and in indicated polar magnetic field strength. Additional data are being assembled.

The elementary theory of magnetic intensification of stellar absorption lines in

the presence of a general magnetic field has been developed during the year. It is shown that the maximum intensification factor for a saturated line in the presence of a strong field is $n/2$, where n is the number of components in the Zeeman pattern. Conditions favoring the effect include high atomic weight, moderate temperature, and, of course, a Zeeman pattern of many widespread components. Many lines of *Eu II* and of *Cr I* are particularly sensitive to magnetic intensification. Evidence for the presence of the effect in α^2 Canum Venaticorum is given in the form of a comparison of theoretical intensification factors with variations in line intensity observed by Struve and Swings. It is apparent that many phenomena observed in spectrum variables still require explanation.

Microphotometer tracings of the spectrum of the white dwarf 40 Eridani B obtained with the analyzer show no evidence of polarization. It is concluded that the great widths of the hydrogen lines in the spectrum cannot reasonably be accounted for by Paschen-Back broadening, as suggested by Blackett.

MISCELLANEOUS

The near-by dwarf star L 726-8 was observed by Joy and Humason at the request of W. J. Luyten. At the time of the first spectroscopic observation with the 100-inch telescope, August 25, 1948, the star was found to be a visual binary. The spectra of both components were estimated as dM5.5e. Measurements of a direct photograph showed a separation of $1''.5$ in position angle 117° . At the time of a second spectroscopic observation, September 25, 1948, one of the components, which could not be identified because of poor seeing, increased its brightness noticeably. The spectrogram showed that the outburst pro-

duced a strong continuous spectrum which nearly blotted out the normal M-type spectrum, the emission lines of hydrogen being strengthened. The line of ionized helium at $\lambda 4686$ appeared in emission. This type of spectral activity had previously been found by Joy in the T Tauri variables and in the bright-line stars involved in the Taurus clouds.

Among the dwarf stars of lowest luminosity, seven were observed whose spectra were dM4 or later but without emission lines. No subdwarf characteristics were seen.

The intensity distribution of the continuous spectrum of the well known subdwarf Wolf 489 was estimated to be about that of a G0 star. No lines could be distinguished in the spectrum.

Sanford has shown that the radial velocities derived from the interstellar Ca II lines in the stars in open clusters, as well as the stellar velocities, manifest differential galac-

tic rotation. Furthermore, there is evidence that both equivalent widths and velocities from the interstellar lines have merit as criteria of distance.

Additional spectrograms of stars of standard spectral types have been obtained. One set, dispersion at $H\gamma$ 35 Å/mm, was obtained largely by A. H. Joy.

Microphotometer tracings of the widened lines in the spectrum of the G-type star HD117555 indicate a rotational speed at the equator of at least 75 km/sec. This observation by Merrill would indicate that hydrogen atoms thrown off from the equatorial zone may be responsible for the bright *H α* line.

Zwicky, Johnson, and A. G. Wilson have completed the coverage of the Milky Way both with direct photographs and with objective prism on the 18-inch schmidt telescope. This provides the base comparison plates for an extensive search for novae in the Milky Way.

GALACTIC NEBULAE AND STAR CLOUDS

PLANETARY NEBULAE

The search for planetary nebulae by Minkowski has led to the discovery of 34 new planetaries during the past year. The total number of planetaries discovered on the 10-inch objective-prism plates is 194. Objective-prism exposures with the 18-inch schmidt have to date led to the identification of 20 new planetaries; a considerable number of objects found with the 18-inch schmidt still remain to be investigated. Of the total of 370 planetaries now known, 114, or almost one-third, appear within 10° of the galactic center. This demonstrates the high concentration of planetaries toward the center of the Galaxy. It is hoped to obtain information on the kinematics of the central region of the Galaxy from an investigation of the radial velocities of planetaries; such an investi-

gation has been started, but no results are as yet available.

The survey of internal motions in the brighter planetary nebulae with the coude spectrograph has now been completed by O. C. Wilson. In general, relatively large velocities of expansion of the nebular shell are found. Except in the case of hydrogen, larger velocities are more normally associated with high-excitation particles than with low-excitation particles. Moreover, slitless spectrograms show that $[Ne\text{ v}]$, which always gives a smaller than average velocity of expansion, also always gives an image slightly smaller than hydrogen, whereas lines of $[O\text{ II}]$ and $[N\text{ II}]$ tend to give slightly larger slitless images. These facts suggest that radiation pressure, arising from radiation produced within the bright rings, is responsible for the observed

effects. Such considerations have led to a somewhat different picture of the structure and dynamics of planetary nebulae from that now current.

NOVA HERCULIS

Plates taken by Baade in the summer of 1948 at the Newtonian focus of the 100-inch telescope show no marked changes in the structure of the ejected shell within the past four years. Images of $\lambda 3727$ [O II] and $\lambda 4959, 5007$ [O III] are elliptical rings with weak condensations at the ends of the major axis. The image of $H\alpha$ $\lambda 6548, 6584$ shows the same remarkable structure noted in 1942.

VARIABLES IN THE NUCLEAR REGION OF THE GALACTIC SYSTEM

The observations of the field around the globular cluster NGC 6522 ($\lambda = 328^\circ$, $\beta = -4^\circ$) were concluded by Baade with extended series of plates taken from July to September 1948. Continued search for variables has brought their number to 284 for the field investigated, or to 750 variables per square degree. Magnitudes for the variables so far found have been estimated by Dr. Sergei Gaposchkin, of Harvard College Observatory. The derivation of the light-curves, the joint work of Dr. Gaposchkin and Dr. Cecilia Payne-Gaposchkin, is completed for more than half the material. The results confirm the earlier surmise of Baade that the stars of the nuclear region of our galaxy belong to population II. Roughly 50 per cent of the variables are cluster-type variables of large amplitude with very asymmetrical light-curves and periods of less than 0.4 days. The semiregular variables come next in frequency.

During the present year observations of

a new field of the nuclear region centered on CD-28°14334 ($\lambda = 332^\circ$, $\beta = -6.5^\circ$) were begun. In contrast with the field centered on NGC 6522, which shows some irregularities caused by absorption, the new field is exceedingly uniform.

STAR CLUSTER WITHIN THE ORION NEBULA

The large star cluster in the Orion nebula recently discovered by Baade, using plates sensitive to the $\lambda 6900$ -7500 region, has been searched for variables. A comparison of two pairs of plates led to the discovery of 50 new objects of this type.

GALACTIC STRUCTURE

With the 48-inch schmidt camera the central region of our galaxy was covered by Baade with red exposures, the exposure times ranging from 1 hour to 3 hours. A search on these plates led to the discovery of a few new globular clusters. All are rather close to the galactic equator (the line of greatest obscuration) and are exceedingly faint.

Baade is making an attempt to single out the near-by spiral arms of our own galaxy, using the highly luminous B and O stars and the emission nebulosities which from studies of the Andromeda nebula are known to occur only in these arms. Because of heavy obscuration, it appears simplest to search for the emission nebulae in $H\alpha$ light. This search will be followed by the identification of exciting stars, and the determination of their spectral types, absolute magnitudes, apparent magnitudes, and color excesses from which distances can be calculated. As a first step in this program, the Milky Way was covered along the galactic equator from $\lambda = 310^\circ$ to $\lambda = 90^\circ$ with red exposures of 1 hour's duration with the 48-inch schmidt camera.

EXTRAGALACTIC NEBULAE

NEBULAR PHOTOMETRY

The program of photometry of the extragalactic nebulae for which Humason has derived velocities has been continued by Pettit with the 1P21 photomultiplier cell, principally with the 60-inch telescope. Magnitudes on the photographic scale and color indices have been obtained for each object. Of over 500 systems, approximately 70 remain to be measured. Many of the remaining systems are large and require measurement of numerous galactic stars. Some systems will have to be measured with the 20-inch telescope.

Of the 175 nebulae measured by Stebbins and Whitford, 22 have been remeasured, one-half of which are indicated by them as being of doubtful accuracy. The average departure regardless of sign is 0.1 mag.

RADIAL VELOCITIES

Final revisions of measured red shifts and spectral types for over 500 nebulae have been completed and are now being prepared for publication by Humason.

Two spectrograms of NGC 4151 have been obtained with the coude spectrograph (10.3 Å/mm) by O. C. Wilson. The emission bands have been measured for wave length on one plate, with the result that $\Delta\lambda/\lambda$ appears to be constant to within about 1 per cent from $\lambda 3400$ to $\lambda 6600$. The second spectrogram is somewhat stronger and shows unmistakable structure in some of the emission bands; no analysis of the structure has yet been attempted.

SURVEY OF THE ANDROMEDA NEBULA

The 100-inch survey of the Andromeda nebula with ultraviolet, blue, red, and near infrared exposures, covering an area 1°5 by 5°0, was practically completed by Baade during the present season. Among the

final results will be a complete list of all emission nebulosities brighter than -3^m (some 300) and a similar number of star clusters to about the same limit.

MEMBERS OF THE LOCAL GROUP

Intercomparisons with Selected Area 68 were made by Baade for both NGC 6822 and the Andromeda nebula, since there exists some uncertainty regarding the magnitude of the brightest stars in these systems. Long exposures of the Andromeda nebula with the 48-inch schmidt in the visual and red regions revealed what appears to be a tidal effect in its elliptical companion, NGC 205. Besides its two axes due to projection, this nebula shows a third axis which is directed toward the center of the Andromeda nebula. This third axis or bar extends in either direction beyond the projected disk of NGC 205.

DISTRIBUTION OF NEBULAE

A substantial part of the first photographs taken by Hubble with the 200-inch Hale telescope and by Hubble, Baade, and Zwicky with the 48-inch schmidt camera were devoted to exploratory investigation of the distribution of extragalactic nebulae in space. Hubble, with the assistance of A. R. Sandage, is studying on some of these plates the distribution of faint nebulae in standard apparently normal regions of the sky.

Almost a dozen distant clusters of nebulae were found in an area of 300 square degrees in Virgo by Baade, and several additional clusters were picked up by Zwicky, especially in the Corona Borealis region. A number of clusters discovered on plates taken with the 48-inch schmidt telescope were checked on plates taken by Baade with the 100-inch. It is obvious from these tests that the few

clusters of nebulae previously known represented a very meager sample indeed, and that the rich material to be expected from the 48-inch schmidt survey will greatly facilitate all investigations in which one must fall back on clusters of nebulae (velocity-distance relations, etc.).

Zwicky has used the 48-inch schmidt plates to study the luminosity function of nebulae, particularly at the low-luminosity end of the distribution-curve. An additional dwarf system was found which presumably is within the perimeter of the local group, and many dwarf systems were picked up which belong to other groups of nebulae. As a limit of dwarf systems, the suspected existence of intergalactic matter was confirmed through some preliminary investigations of the central regions of the Coma cluster, where luminous intergalactic matter seems to be recorded on the 48-inch schmidt plates over a region about one-half million light-years in diameter.

The work on the constitution of clusters of nebulae with the 18-inch schmidt was continued by Zwicky and was extended to the 48-inch schmidt for the Cancer cluster and the Coma cluster. The studies made originally with the 18-inch were corroborated; in particular, it was found that bright and faint nebulae segregate in the sense of heavy and light masses in a Boltzmann assembly.

An area 18° by 18° covering the Virgo cluster was photographed by Baade. The plate material will permit an accurate classification of all members of this cluster, since the scale of the 48-inch schmidt ($1 \text{ mm} = 67$ seconds of arc) is large enough for study of the detailed structure of the nebulae.

Plates taken by Baade in connection with a study of the group of nebulae associated with M 81 and 101 revealed a third dwarf member associated with the physical pair NGC 5236 and 5253.

THEORETICAL STUDIES

The so-called galactic radio noise has been studied theoretically by Greenstein. Since it may originate in thermal agitation in interstellar clouds of ionized hydrogen, an attempt has been made to determine the effective optical thickness of the ionized regions in our galaxy. This appears to be small except along the spiral arms, and galactic radio noise, if produced in interstellar space, should come only from the spiral arms.

With Professor Leverett Davis, Greenstein has developed a theoretical explanation of the recently observed polarization of light transmitted through interstellar clouds of absorbing dust particles. If the particles are not spherical but elongated, as most crystalline materials are, they absorb light preferentially of a plane of

polarization perpendicular to their long axes. To produce observable polarization, the long axes should remain nearly parallel over long regions in space. This orderliness is disrupted by the bombardment of the particles by the interstellar hydrogen. At $10,000^\circ \text{ K}$, an average collision with hydrogen produces an angular velocity of the particle of 10^8 radians per second. Thus only at very low temperatures (10° K) will there be orderliness unless a decelerating mechanism is found. If the particles have some ferromagnetism, their rotation in a galactic magnetic field will dissipate energy and slow them down, by hysteresis. A field of 10^{-4} gauss is required. Recent theoretical progress suggests that perhaps the particles may continue to spin and nutate about the magnetic fields, with

a statistical preference for the long axis to lie perpendicular to the field. A much smaller field, with smaller energy loss, is then required. The existence of a magnetic

field, either general or associated with the interstellar clouds, is of significance in recent theories of the production and trapping of cosmic rays.

INSTRUMENTATION

The program for ruling improved gratings for spectrographs of the 200-inch Hale telescope and other instruments has been actively pushed by Prall under the supervision of H. D. Babcock until February 1, 1949, and of H. W. Babcock since that date. Between April and December 1948, five large gratings (6 by $7\frac{1}{2}$ inches) of excellent resolving power were made, and during this period the advantages of the graphite-on-diamond end-thrust bearing for the screw were proved. In 1949, three additional 6 by $7\frac{1}{2}$ -inch gratings have been ruled, as well as one slightly smaller. There has been a progressive rise in the quality of the gratings as small residual sources of error have been reduced or eliminated. Periodic error has been reduced to such a level that Rowland ghosts have intensities of less than 0.5 per cent in the sixth order, with normal slit widths. Ghosts are not seen in useful orders of the latest gratings. The periodic error has

been practically eliminated by the use of a cam which introduces a compensating periodic displacement of the grooves having an amplitude of 3×10^{-7} inch. One remaining problem is connected with proper lubrication of the ways of the diamond carriage when long grooves are ruled; this seems to represent the one serious obstacle to the production of gratings of high quality.

The integrating exposure meter for the coude spectrograph has been rebuilt by H. W. Babcock on a new design. It is superior to the old one and has proved useful in routine work for several months.

A low-dispersion grating spectrograph for use in nebular studies at the Newtonian focus of the 100-inch telescope was designed by Nichols and Minkowski and constructed in the Observatory shop. It uses one of the gratings recently ruled by Prall and Babcock.

GUEST INVESTIGATORS

In addition to the permanent staff, a substantial number of guest investigators from other institutions have made use of the facilities of the Observatories to obtain material for their studies. Plates already in our files have been used, and additional observations have been obtained with the large telescopes.

Dr. Lyman Spitzer, Jr., of the Princeton University Observatory, continued his investigations of interstellar absorption lines during the fall of 1948. About one hundred of Adams' high-dispersion plates showing

interstellar K and H were microphotometered to obtain equivalent widths of these lines and their components. New plates of some 20 stars were taken in the yellow, in a search for components of the interstellar D lines. About half of these showed complex structure, with components at the same radial velocities found by Adams in K and H. In addition, a search was made for interstellar *Li* and *Be* lines, with negative results. If the abundance of *Be* relative to *Na* is the same in interstellar matter as in the earth and in meteorites, this ele-

ment should be about at the threshold of measurement with the 32-inch camera used.

In the summer of 1948 Dr. A. E. Whitford, of Washburn Observatory, University of Wisconsin, extended the previous study of colors of remote extragalactic nebulae to include spirals in the Corona Borealis cluster. In the small sample available, late-type spirals do not show the excess reddening found in elliptical nebulae in the same cluster. This observation supports Schwarzschild's suggestion that near-by elliptical nebulae have become bluer in the past hundred million years, owing to the burning out of the red supergiants. The photoelectric calibration of magnitudes and colors of stars in Selected Areas 57 and 61, begun by Dr. Joel Stebbins in 1947, was continued, and work started on Selected Area 68. The study of interstellar reddening out to 2 microns, begun in 1947, was extended to several additional highly reddened B stars, using an improved lead sulfide photometer with refrigeration.

Dr. John C. Duncan, of Whitin Observatory, Wellesley College, continued his photographic studies of nebulae. Negatives were obtained with the 18-inch schmidt camera and red-sensitive films which showed much more extensive nebulosities in the Cygnus region than had previously been observed.

During the summer of 1948 Dr. George Herbig, on leave from the Lick Observatory as a National Research Fellow, made a study, on coudé plates, of the occurrence of the titanium isotopes in M-type stars in which the titanium oxide bands appeared in adequate strength. A precise determination of the abundance ratios was not feasible owing to the photometric and other difficulties inherent in quantitative work with such heavily lined spectra, and to the present impossibility of identifying all the

TiO lines which were confused with the weak isotope features. The results indicate that, in the stars examined, and within the rather large uncertainty of the observations, there are no large deviations from the isotopic constitution of terrestrial titanium. Certainly there is no enhancement of the relative abundance of any of the rarer titanium isotopes in the M-type stars such as is apparently observed for C^{18} in some carbon stars.

A rather strong molecular absorption band with head at $\lambda 3682$ was found by Merrill and Joy in the spectra of a number of long-period variables. Herbig identified this band with ZrO by comparison with a spectrogram of the zirconium arc in air taken by Dr. R. B. King. The rotational structure of the band on the laboratory plate is that to be expected of an electronic transition with $\Delta\Lambda=0$; a $^1\Sigma \rightarrow ^1\Sigma$ transition seems most probable. If this is the case, this band is probably the (0,0) head of a new system of ZrO.

The "channeled" appearance of the $H\beta$ line in Omicron Ceti was shown to be due largely to absorption by rotational structure of the (2,0) and (3,1) bands of the blue-green system of titanium oxide.

In two visits to the Observatories in 1948 and 1949, Dr. Sergei Gaposchkin, of the Harvard College Observatory, carried out an extensive investigation of variables in the vicinity of the galactic nucleus around the globular cluster NGC 6522. Estimates were made of the brightness of several hundred variables, previously discovered by Baade on over 100 plates of this region. The classification of the variables on the basis of these measures was used for a general discussion of the problem of the population of the galactic nucleus. In addition, some colorimetric studies of the globular clusters NGC 6522 and 6528 and a spectroscopic investigation of a few in-

dividual stars such as SX Cassiopeiae and AE Aquarii were carried out.

During the summer of 1948 Dr. Cecilia Payne-Gaposchkin, of the Harvard College Observatory, examined and classified over 2000 spectra of cepheid variables, cluster-type variables (RR Lyrae stars), and RV Tauri stars, from the Observatories' files. For some stars (especially on spectra of higher dispersion) the intensities of selected lines were estimated by eye in lieu of classification. The material obtained from this examination is being used for the formation of mean spectral and velocity curves of these stars as a function of their period, and for an analysis of the atmospheric and physical conditions of the stars.

Dr. Daniel M. Popper and Dr. Everett C.

Yowell, of the University of California at Los Angeles, have carried out spectroscopic observations of a group of eclipsing binaries.

A study of the intensities of the lines of C, N, O, Ne, Mg, Al, Si, and S has been undertaken for early B stars by Dr. Lawrence H. Aller, of the University of Michigan, using coude plates from the Mount Wilson Observatory files. The survey includes nearly all objects with sharp lines between O and B5. These intensities are being used for a determination of the abundances of these light elements.

Mr. W. C. Miller and Dr. A. G. Mowbray, both of Pasadena, have made further important contributions to the Be star program by obtaining many slit spectrograms with the large telescopes.

THE LIBRARIES

During the year 1948-1949 the library on Santa Barbara Street has acquired 562 volumes, 276 by gift, 103 by purchase, and 183 by binding, making a total of 16,892 volumes. Volumes from the Hale collection still form a large proportion of the gifts, but a number have come from other sources, including a selection from Dr. Pease's library, presented by the executor of his estate. His copy of Smith's *Optics*, 1738, is an excellent addition to the collection in the Hale Room.

About 500 volumes have been selected from Dr. Hale's library to send to Palomar Mountain, for the book room of the 200-inch Hale telescope. Some of these are duplicates of astronomical books already in both the Santa Barbara Street and Robinson Laboratory libraries; others, of a more

general scientific character, will furnish good reading during inclement weather.

To the 4000 volumes in the library at Robinson Laboratory, 387 volumes have been added during the year: 141 by purchase, 22 by binding, and 224 gifts. Among the latter, 85 volumes came from Mrs. Richard C. Tolman as a memorial to Dr. Tolman, 24 from the Bateman library, and 82 from the Hale, Pease, and van Maanen collections. Although not yet complete, particularly in reference works, this "working library" began in the fall of 1948 to serve the new department of astronomy of the California Institute of Technology and those staff members of the Mount Wilson and Palomar Observatories whose offices are in Robinson Laboratory.

STAFF AND ORGANIZATION

Dr. Alfred H. Joy retired on October 1, 1948 after thirty-three years as a member of the staff of the Observatory. After first

participating in the solar program of the Observatory, Dr. Joy gradually shifted his efforts to stellar spectroscopy. He col-

laborated extensively with Dr. Adams in the study of the effect of absolute magnitude on stellar spectra and in the use of these relationships for the determination of stellar parallaxes. In recent years Dr. Joy has investigated the spectra of a large number of variable stars. These studies have very substantially advanced our knowledge of the classification and characteristics of this difficult group of objects. Radial-velocity measurements of these stars have been applied by Dr. Joy to studies of galactic rotation and similar problems.

From 1920 until his retirement Dr. Joy held the post of Secretary of the Observatory. In this position he very ably handled most of the official correspondence. He was also responsible for the public relations of the Observatory, including arrangements for visitors, press releases, and the preparation of official literature. Mr. Milton Humason was appointed Secretary of the Observatory on Dr. Joy's retirement.

Miss Cora Burwell retired on July 1, 1949 after forty-two years of service on the computing staff of the Observatory. In addition to assisting in many investigations in the field of stellar spectroscopy, she was co-author of the very extensive *Mount Wilson catalogue of B- and A-type stars having emission lines*.

Mr. Edison Hoge transferred to the Hydrodynamics Laboratory of the California Institute of Technology in March 1949. For twelve years Mr. Hoge had been in charge of the photographic laboratory of the Observatory and had assisted in the observations of the solar department. Mr. William Miller was appointed photographer and will devote his whole time to the photographic laboratory. Simultaneously much of the routine photographic finishing work of the Observatory was transferred to the photographic laboratory of the California Institute. With these

changes it is expected that the photographer will be in a position to carry out regular tests of the speed and color sensitivity of each batch of plates used by the Observatories. He will also investigate methods of hypersensitization and other procedures designed to obtain the maximum effectiveness of the plates when used for the long exposures that are necessary in most astronomical investigations.

RESEARCH DIVISION

Solar Physics: Seth B. Nicholson, Edison R. Hoge, Edison Pettit, Robert S. Richardson, Joseph O. Hickox, Irene Whitney.

Stellar Spectroscopy and Motions: Paul W. Merrill, Horace W. Babcock, Ira S. Bowen, Jesse L. Greenstein, Milton L. Humason, Alfred H. Joy, Rudolph Minkowski, Roscoe F. Sanford, Olin C. Wilson, Ralph E. Wilson, Fritz Zwicky, Sylvia Burd, Cora G. Burwell, Mary F. Coffeen, A. Louise Lowen, Barbara Olsen.

Nebular Photography, Photometry, and Spectroscopy: Edwin P. Hubble, Walter Baade, Milton L. Humason, Josef J. Johnson, Rudolph Minkowski, Edison Pettit, Albert G. Wilson, Fritz Zwicky, Alice S. Beach.

Secretary of the Observatory: Milton L. Humason

Editor: Paul W. Merrill

Assistant Editor and Librarian: Elizabeth Connor

Photographer: William C. Miller

INSTRUMENT DESIGN AND CONSTRUCTION

Design: Bruce Rule, project engineer; Edgar C. Nichols, chief designer; Harold S. Kinney, draftsman.

Optical Shop: Don O. Hendrix, superintendent; Floyd Day, Melvin Johnson, opticians.

Instrument Shop: Albert McIntire, superintendent; Elmer Prall, instrument maker; Fred Scherff, Oscar Swanson, Albert Labrow, Donald Yeager, machinists.

MAINTENANCE AND OPERATION

Mount Wilson Observatory and Offices

Office: Anne McConnell, bookkeeper; Wilma Berkebile, secretary; Dorothea Otto, stenographer and telephone operator.

Operation: Ashel N. Beebe, superintendent of construction; Hugh Couch, carpenter; Kenneth de Huff, engineer; Murdoch McKenzie, janitor and relief engineer; Thomas A. Nelson, Ralph Bennewitz, Eugene Hancock, night assistants; Emerson W. Hartong, truck driver and machinist helper; Anthony Wausnock, Margie Wausnock, Alexander Kochanski, stewards; Arnold T. Ratzlaff, Homer N. Joy, janitors.

Palomar Observatory and Robinson Laboratory

Office: Eleanor G. Crawford, secretary and librarian; Dorothea Davis, secretary.

Operation: Byron Hill, superintendent, Palomar Observatory; Fred Feryan, Gladys M. Feryan, Harley C. Marshall, George W. Pettit, Joe Stehlik, Benjamin B. Traxler, Gus Weber, Raymond L. White.¹

¹ The Palomar Observatory is still in a transition stage from construction to operation. In most cases the final positions in the operating organization have not been assigned at the time of this report.

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GEOPHYSICAL LABORATORY

Washington, District of Columbia

LEASON H. ADAMS, *Director*

Research may be likened to the exploration of a series of small fields spread in a broad pattern over the landscape and traversed by a network of paths along one of which the investigator chooses to proceed, pausing now and then to observe, to ponder, and to experiment. He seeks to understand all that he perceives; and if after a while he is satisfied with what he has learned in one particular field, he passes on to another, sometimes following along the original path and sometimes along an intersecting one. Steadily he pushes forward from that which is known into that which is unknown and, therefore, mysterious. As he acquires experience and confidence, he is encouraged to enter areas of greater complexity and to attack more formidable problems.

Usually the true scientist finds the greatest satisfaction in extending the limits of knowledge and selecting paths that lead into new fields of inquiry, but it may happen that in undertaking step by step the solution of one of nature's broad-gauge problems, he finds that the path he must follow to success will turn back toward its starting point. Two striking examples of the way in which fruitful research may curve back on itself after many years are furnished by the Geophysical Laboratory's current program in experimental petrology. Although this is a forward-looking program and advances are being made into hitherto unexplored fields, it has seemed desirable also to re-examine two old subjects because of an increasing realization of their place as key factors for the unraveling of some mysteries concerning the formation of the rocks of the earth's crust.

These two items are the minerals feldspar and quartz.

Probably the most important group of rock-forming minerals consists of the feldspars, which are aluminosilicates containing other oxides, principally lime, soda, and potash. The first paper published from the Laboratory (1905), entitled *The isomorphism and thermal properties of the feldspars*, is a monograph now generally considered to be one of the great classics of petrology and to have laid the foundation for the subsequent program of silicate research. Day and Allen gave the first proof that the interrelationships and genesis of minerals may be studied with success by quantitative laboratory methods. Their work still evokes the admiration of the most critical, and it was done the hard way. Improved experimental methods, especially the quenching techniques and the automatic control of temperatures, were developed later, but these investigators had to make use of the method of heating curves in its most difficult application, and they were obliged to regulate temperatures laboriously by hand for long periods of time.

After the quenching method was developed, several years later, it was applied to the feldspars with resulting refinement of the original work. Feldspars are found as mineral phases in many of the silicate "systems" that have been studied at the Geophysical Laboratory, and there has been a strange lack of correlation between the synthetic feldspars and the natural ones. Pure feldspars made in the laboratory show an unbroken series of solid solutions, but careful determination of the

crystal structure of natural feldspars reveals that the two end members of the plagioclase series, albite and anorthite, have certain differences of lattice structure which seem to forbid belief that they could form a joint lattice with continuous range in composition from end to end. Also, in the laboratory the soda feldspar, albite, and the potash feldspar, orthoclase, form complete solid solutions; but in deep-seated rocks, where the concentration of potent volatile fluxes may be greater by reason of greater pressure, and where the temperature of crystallization is lower, albite containing very little potash and potash feldspar with only moderate amounts of soda are found side by side. Moreover, artificial crystalline albite does not have properties corresponding to those ordinarily given for natural albite. The field evidence, then, has seemed to run counter to the laboratory evidence.

The reason for this seeming lack of desired correlation between natural and artificial feldspars is becoming evident from the new work, made possible on the one hand by improved methods of subjecting materials to the simultaneous action of high temperature and high pressure in the presence of water, and on the other hand by the commercial development of new types of X-ray spectrometers. The recent investigations have shown that the difference between natural albite, as usually found, and artificial albite is that the natural albite is a low-temperature form. This dual character is exhibited by other plagioclases as well as by albite, and is especially marked in feldspars close to albite in composition.

Furthermore, the peculiarities in the alkali feldspars are now seen to be a consequence of an unmixing at lower temperature of the continuous series of solid solutions that may form at high temperatures. The extent of this unmixing depends on

the temperature; and, by a special technique the essence of which is to measure very precisely one of the crystal spacings, it is possible to determine rapidly and easily the compositions of the feldspars formed at any temperature. The situation with respect to the plagioclase feldspars has not yet been cleared up completely, but the indications are that by means of the new methods it will be possible to determine the temperature of formation of any pair of feldspars associated in a single rock.

Thus, it may be seen that the return to one facet of an old problem, after improved apparatus and techniques became available and after further field evidence was obtained, has led to a major advance in our knowledge of the minerals of which igneous rocks are composed. Previous discrepancies are being removed and a possible method for determining the temperature of mineral formation has resulted.

A second area of early exploration to which the orderly prosecution of silicate research has impelled us to return is the fundamental nature of the mineral quartz. This and other forms of silica have been subjected to study from the early days of the Geophysical Laboratory. In 1906 Day and Shepherd described a method for making clear and bubble-free silica glass by fusing quartz crystals under pressure—a method that subsequently was adopted by industry. The use of quartz as a geologic thermometer was suggested in 1909; Fennel's classic work on the various forms of silica and their mutual relations appeared in 1913; and the effect of pressure on the high-low inversion of quartz was studied in 1928.

The transformation of quartz at 573° C. from one crystalline form to another is one of the important characteristics of this mineral. Up to the present it has been considered to be a fixed point, like the melting point of pure ice, independent of

the origin and previous history of any particular sample. Recent work with improved apparatus, details of which are presented in a later section, has cast doubt on the immutable character of this transformation. Indeed, parts of the same crystal may show transformation temperatures that differ by a large fraction of one degree, and individual samples of quartz may vary by nearly 2° . It is not yet possible to give a complete explanation of the

variations found in natural quartz, but enough has already been learned to justify the conclusion that the variations in properties of quartz from different localities will provide a new geological thermometer for indicating the temperature and the general conditions prevailing in rocks with which quartz is associated.

The following is an account of the principal investigation carried forward during the past year.

ANHYDROUS SILICATES

METHOD OF STUDY OF COMPLEX MIXTURES

Knowledge of the melting relations of anhydrous silicate mixtures is of fundamental importance in the application of physical-chemical methods to problems of rock formation. Much of the past work of the Laboratory has been on dry melts, from which has come information of basic interest not only in connection with the Laboratory's problems, but also in connection with those of industry. This work has progressed from the simple to the complex, the complexities arising almost entirely from the difficulty of comprehending and explaining melting relations in systems of several components.

In studying these multicomponent systems, it is our practice to separate the various systems into smaller parts, each of which can be treated as a unit. One object of this is to simplify both the theoretical discussion and the practical work. For example, the ternary system nepheline—diopside—silica, discussed below, is part of the quinary system $\text{CaO—MgO—Na}_2\text{O—Al}_2\text{O}_3\text{—SiO}_2$; but it is a part which can be studied and discussed as a unit. Another reason for the separation of a complex system into simpler parts is that we are thus able to approach our objective by a series of steps each of which may be con-

sidered a research that is complete in itself. Although a full knowledge of all the interrelations of all the rock-forming constituents is a goal to be attained in the far-distant future, we advance toward the goal in such a way that our progress may be described in terms of completed projects.

This method of subdividing a complex system is illustrated by current work on the four-component system $\text{K}_2\text{O—MgO—Al}_2\text{O}_3\text{—SiO}_2$. Here the compositions are represented graphically by means of a tetrahedron, but to minimize the necessity for trying to think in terms of three-dimensional space, the system is separated into smaller parts by treating each group of three compositions as end members of a triangular "join." This is equivalent to passing a plane through these three points in the tetrahedron. Such a join may be a true ternary system, by which is meant that, when any mixture of the three end members is melted and crystallized, all compounds and compositions remain within the triangle. An example of this situation is the join leucite—ferrosterite—silica, discussed in last year's report, on which additional measurements have been carried out.

This condition is not found in the join leucite—clinoenstatite—potassium tetrasilicate, also discussed last year, on which im-

portant progress has been made. During crystallization of mixtures in this join, the compounds $2\text{MgO} \cdot \text{SiO}_2$ and $\text{K}_2\text{O} \cdot 5\text{MgO} \cdot 12\text{SiO}_2$ are formed, and, since these are outside the plane under consideration, the resulting residual liquid also must be outside, and on the opposite side, of the join. In spite of such complications, the study and discussion of the quaternary system is always greatly facilitated by separating it into smaller portions. Much progress has been made on the joins mentioned in last year's report and on some additional ones.

THE JOIN JADEITE—ACMITE IN THE
QUATERNARY SYSTEM Na_2O —
 Al_2O_3 — Fe_2O_3 — SiO_2

Substantial progress has been made on the study of other anhydrous systems. Some of this has been motivated, in part at least, by the puzzling problem of the mineral jadeite ($\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2$). The stability relations of jadeite are not known, and it never has been made in the laboratory. Previous studies have shown that natural jadeite on being heated begins to decompose as low as 800°C . and that at about 850° it melts to a clear glass which later crystallizes to nepheline and albite.

Since some of the natural pyroxenes are solid solutions of jadeite and its ferric iron analogue, acmite ($\text{Na}_2\text{O} \cdot \text{Fe}_2\text{O}_3 \cdot 4\text{SiO}_2$), it was believed that a study of the join jadeite—acmite would be desirable and might clarify the stability relations of jadeite. During the past year nine compositions between jadeite and acmite have been prepared, and these are now being studied. For those compositions between 100 per cent acmite and 20 per cent acmite, the primary phase is hematite or a hematite-corundum solid solution. Between 100 per cent and 80 per cent jadeite, the primary phase is a nepheline-albite solid solution. As a consequence, during crystal-

lization of all melts in the join jadeite—acmite, the composition of the liquid phase leaves the join, and its behavior may be described only by reference to the quaternary system Na_2O — Al_2O_3 — Fe_2O_3 — SiO_2 . For those compositions in the join between 100 per cent acmite and 48 per cent acmite, the primary phase (hematite or a hematite-corundum solid solution) is next joined by acmite (or an acmitic pyroxene) below liquidus temperatures. For those between 52 per cent and 80 per cent jadeite, the second solid phase to appear is a nepheline-albite solid solution; and for those between 80 per cent and 100 per cent jadeite, the second solid phase to appear is a hematite-corundum solid solution. At subliquidus temperatures, and especially where only a small amount of a liquid phase is present, equilibrium between crystals and liquid is attained only slowly, and some necessary runs of long duration are now in progress. The fine-grained crystalline phases present at the completion of a run are being identified by their X-ray diffraction patterns.

THE JOIN JADEITE—DIOPSIDE AND COMPOSITIONS IN THE JOIN NEPHELINE—
DIOPSIDE—SILICA

Some years ago fifty separate compositions in the triangular join nepheline—diopside—silica were prepared, and from time to time as the opportunity occurred the liquidus relations in this join were determined. This triangular join is not ternary and is a plane in the quinary system CaO — MgO — Na_2O — Al_2O_3 — SiO_2 . Some of the fifty compositions prepared were chosen to lie in the joins albite—diopside and jadeite—diopside. The results (which have not yet been published) show that albite—diopside is not a binary system and that between pure albite and 90.5 per cent albite the primary phase is not pure albite, but an albite-rich plagi-

clase. The join jadeite—diopside cuts the fields of nepheline-albite solid solutions, plagioclase, and diopside. The observation that those compositions in this join which lie in the diopside field do not reach the boundary surface plagioclase—diopside at the same temperature indicates that the diopside is not pure $\text{CaO} \cdot \text{MgO} \cdot 2\text{SiO}_2$, but a more complex pyroxene.

During the past year the subliquidus relations in the join jadeite—diopside have been investigated in greater detail, and the solid phases have been identified by means of X-rays. No jadeite has been encountered at the temperatures investigated. Those compositions in the triangular join nepheline—diopside—silica near the side line nepheline—diopside have been completely crystallized, and a study of the solid phases is now in progress. These studies should throw light on the mutual stability relations between nepheline, forsterite, diopside, melilite, and plagioclase.

THE QUATERNARY SYSTEM MAGNESIA— FERROUS OXIDE—ALUMINA—SILICA

During the past year some further data were obtained on subliquidus relations in the join $\text{FeO-Mg cordierite--Fe cordierite}$. Primary phases encountered in the join are only three: mullite, spinel, and wüstite. Cordierite is obtained only as a subliquidus phase in the mullite field and in the low-iron part of the spinel field in mixtures containing up to about 40 per cent FeO . At around 50 to 60 per cent FeO in the spinel field, a pyroxene is obtained as a subliquidus phase. Charges containing more than 60 per cent FeO , still in the spinel field, are opaque on quenching because of rapid growth of dendrites of fayalite and possibly wüstite below the liquidus, with the result that it is very difficult to establish the liquidus temperature.

It is planned to continue the laboratory study by completing two additional joins: $\text{Mg cordierite--clinoenstatite}$, and $\text{Mg cordierite--SiO}_2\text{--FeO}$. Both these planes should intersect the cordierite phase volume and assist in outlining the stability relations within the tetrahedron, besides supplying valuable data on the cordierite solid solution series.

Some investigation was made of the factors that influence the attainment of equilibrium between metallic iron (of the crucible) and iron-bearing silicate melts. As a result of previous work it is known that in a neutral atmosphere an equilibrium condition is reached between the metallic iron and the ferrous and ferric iron in a melt. In the course of attaining this equilibrium (minimum of ferric iron), there is a consequent change in the total iron content of charges, the composition changing along a line that on the diagram may be drawn through the FeO corner and the point representing the initial composition. It was found that the amount of change of total iron content of a charge depends primarily upon the total available oxygen in the surrounding gas. Charges heated above the liquidus in an iron crucible sealed in evacuated silica glass tubes for periods up to 14 hours show only slight change (maximum 2 to 3 per cent) in total iron content. On the other hand, charges heated for 2 hours in an atmosphere of purified nitrogen change by an amount which varies from 5 to 15 per cent, or more, dependent upon the partial pressure of oxygen in the nitrogen. The previously used technique for purifying the nitrogen supply was improved by passing the tank nitrogen through cleaned steel wool at 700° to 800° and by reducing the resultant oxide coating on the steel wool with a slow stream of hydrogen fed through overnight between runs.

STUDIES ON THE INVERSION CHARACTERISTICS
OF QUARTZ

Preliminary studies on the inversion temperature of quartz (see last year's report) indicated that the temperature of the high-low inversion of quartz varies by almost 2° in different samples. This variation is apparently related to the geologic environment in which the quartz was found, and there are grounds for believing that with sufficient information on the behavior of a variety of samples of natural and synthetic quartz it will be possible to make a direct correlation between the inversion characteristics and the conditions of formation.

A new method has been developed for studying the inversion and specifically for measuring the magnitude of the heat effect, the temperature at which the inversion begins, and the temperature range through which the transition takes place.

The present apparatus for determining the inversion characteristics involves the use of a silver sample block with four chambers in which are placed crushed and sized samples of the quartz, cryolite (Na_3AlF_6), arkanite (K_2SO_4), and granular alumina. Cryolite and arkanite have inversions at 562° and 584° , respectively, and give reference temperatures for the quartz inversion, which is at 573° . Thermoelements of gold palladium-platinum rhodium are placed in each of the four materials and connected in such a manner that no electromotive force is generated when all four materials are at the same temperature. If, on cooling or heating, any of the materials absorbs or gives off heat, its temperature will be temporarily above or below that of the others, and an emf will be produced, which deflects a sensitive galvanometer. The galvanometer deflec-

tion is recorded on a Brown strip chart recorder by means of a light spot reflected from the galvanometer mirror and falling on a divided photocell connected so as to form a "light-follower" circuit.

Preliminary runs with the apparatus showed that the inversion temperature of a quartz sample can be bracketed between the cryolite and arkanite inversions with an error of repetition of less than 0.05°C . The preliminary and calibration runs also show that some quartz samples differ from others not only in temperature of beginning and duration of inversion, but also in the magnitude of the thermal effect accompanying inversion and in the amount of hysteresis between heating inversion and cooling inversion. All quartz samples studied also exhibit an as yet unexplained difference between the temperature of beginning of inversion in the initial heating run and the temperature of beginning of inversion in subsequent runs.

One particularly interesting quartz specimen from Minas Geraes, Brazil, is a perfectly clear and colorless crystal the basal part of which was formerly used as the reference quartz. Upon exposure to X-rays, sections of the crystal are selectively colored and exhibit three distinctly separate growth zones. The inner and outer zones of this crystal have inversion temperatures which differ by from 0.6° to 0.8° , the greater difference being obtained on cooling. It appears that a further detailed study of even this one crystal may furnish a valuable clue to the relation between inversion temperature and structure and composition, and measurements on quartz samples prepared in the laboratory under controlled conditions may provide quantitative relationships for making quartz a reliable geological thermometer.

SILICATES IN THE PRESENCE OF WATER UNDER PRESSURE

Fundamental though they are to geology, the results of studies of dry systems cannot be applied directly to many geological problems without some knowledge of the effect of volatile components, especially water, in altering the phase-equilibrium relations. Water is an essential constituent of rock magmas, and its presence in magmatic systems raises many problems both theoretical and experimental. The techniques that have been developed will carry us a long way toward the solution of such problems. The positive control of pressure obtained by the use of a pump with a pressure regulator to inject water into the pressure vessel has increased both the ease of manipulation and the certainty of results and has eliminated the doubtful calculation of pressure by means of equations of state known not to be applicable. Two successful types of pressure vessel are in daily use; both offer possibilities for almost unlimited investigation in fields that are just being opened up.

FELDSPARS

Among rock-forming minerals the feldspars are of the highest importance. In the igneous rocks of the accessible crust of the earth they far outweigh all other minerals in abundance; in the metamorphic rocks they are but little less important; in sedimentary rocks they occur not merely as detrital grains derived from other rocks, but also as new, autigenic growths. It is only natural that the feldspars have been much studied and that more is known about them than about any other rock-forming mineral group. As is ever true in scientific investigation, the knowledge gained serves to reveal and to emphasize what there is yet to learn.

Studies are now being carried out that are designed to throw further light on the

conditions under which feldspars develop. The work consists principally of laboratory experiments in which feldspars are grown under a wide range of measured pressures and temperatures, followed by determination of the properties of the feldspars and the manner of the variation of these properties with the controlled conditions of their growth, and this again by careful measurement and comparison of the properties of the synthetic feldspars with those of natural feldspars of widely variant geologic environment. By reason of the ubiquitous character of natural feldspars, it is expected that quantitative knowledge of the conditions of formation of a wide range of natural rocks will thus be greatly extended and refined. Significant progress has been made, some details of which are now presented.

There are three principal feldspars: potash feldspar (KAlSi_3O_8), soda feldspar ($\text{NaAlSi}_3\text{O}_8$), and lime feldspar ($\text{CaAl}_2\text{Si}_2\text{O}_8$). No natural feldspar ever has the composition indicated by any one of these chemical formulas. They are always mixtures of the three, not mechanical mixtures but true solid solutions, or "mixed crystals." In the language of the theory of phase equilibrium, these chemical compounds are the components of the solid solutions; or in the language of crystal-structure theory, K, Na, and Ca (also Si and Al) can proxy for each other in the crystal lattice within certain limitations which are variable and whose variation is controlled by the conditions of formation of the feldspar—and, of course, by the composition of the medium (solution or melt) from which the crystals formed.

The components of the feldspars are also conveniently referred to by mineralogists as end members; and mineral names are given to these end members, the soda

feldspar being known as albite, the lime feldspar as anorthite, and potash feldspar as orthoclase or microcline depending on its crystal form. Pure albite, anorthite, and orthoclase can be made in the laboratory, but, as has been noted, when formed in nature each of them contains some of the others. Certain occurrences of albite are known in which there is a total of little more than 1 per cent of anorthite and orthoclase. Usually, however, significant or even notable amounts of all three components enter into the composition of the natural crystals, though the potash component is always low when the lime component is high.

We may now state in more specific terms the special problems posed by the feldspars. Igneous and other rocks contain feldspars that appear to show every gradation of composition between albite and anorthite; and these two components have, therefore, been regarded as forming an unbroken series of solid solutions known as the plagioclases. Plagioclase is the principal constituent of the most common lava flows, the basalts. Early studies at this Laboratory of the melting temperatures of pure synthetic mixtures of these components seemed to confirm the view that an unbroken series exists. On the other hand, examination of natural feldspars by the new and powerful methods of X-ray diffraction shows that anorthite and albite have differences in atomic arrangement that seem to preclude the possibility of continuous and complete substitution of one end member for the other. It is possible that at high temperatures the lattices are such that unbroken gradation of composition can occur, but that at the ordinary temperatures at which X-ray studies have been made this situation no longer prevails. The solution of this particular feldspar problem is important because, if the plagioclases represent an unbroken series,

the composition of a plagioclase occurring in any rock will depend only upon the composition of the medium from which it is formed; if, on the other hand, the series has a hiatus at some temperatures, then the composition of a plagioclase will depend as well upon the temperature at which it is formed. It thus might prove possible to determine the temperature of formation of any plagioclase.

Over against the great subgroup of lime-soda feldspars known as the plagioclases stand the other subgroup commonly referred to as the alkali feldspars. These are potash feldspar, occurring in nature in two principal forms, orthoclase and microcline, and the soda feldspar, albite. Albite is thus a member of both subgroups. The sodic end member of the plagioclases is sufficiently like potash feldspar in mode of genesis to warrant grouping them together. Not only that, but these two feldspars also form solid solutions, that is, homogeneous crystals which are intermediate between them in composition. These alkali feldspar solid solutions show much more complicated relations than the plagioclase series have usually been regarded as showing.

Crystals of alkali feldspars, when formed as early crystals in lavas and, therefore, presumably grown at high temperatures, may show a wide range of mutual solid solution of the potash and soda components. On the other hand, when grown in deep-seated rocks, probably in the presence of volatile materials held in by the greater pressure, with consequent lowering of the temperature of crystallization, the soda and potash feldspars in nearly pure form occur side by side as separate crystals. In natural rocks the indications are, therefore, strong that in this series of feldspars the extent of solid solution is a function of temperature.

In order to determine the quantitative aspects of the relation thus qualitatively

stated, studies have been made on the behavior of mixtures of various compositions between $\text{NaAlSi}_3\text{O}_8$ and KAlSi_3O_8 in the presence of water vapor, which is the principal natural volatile flux, at pressures up to 2000 atmospheres and at temperatures up to those at which the mixtures are completely liquid. In the language of phase-equilibrium theory, we have investigated the liquidus, solidus, and subsolidus relations in the system $\text{NaAlSi}_3\text{O}_8$ — KAlSi_3O_8 — H_2O at various pressures. The synthetic mixtures approach closely the composition of the natural volcanic rock trachyte and its deep-seated equivalent syenite, since these rocks consist essentially of alkali feldspars.

A necessary, or at least a most desirable, preliminary to the study of any system having water as one of the components is a study of the system without water, in this case the system $\text{NaAlSi}_3\text{O}_8$ — KAlSi_3O_8 . Fortunately this work had previously been done, and in addition we were fortunate in having many mixtures available for our studies with water, for the mere making of the mixtures is in itself no mean task. Since liquids of these compositions are extremely viscous, attainment of a homogeneous liquid requires long periods of special treatment.

The extreme viscosity of the liquids also introduces great difficulties in the attainment of equilibrium between crystals and liquid, but these have been overcome by increasing the time factor, and a satisfactory equilibrium diagram for the system without water (the dry system, as it is called for convenience) is available. This diagram gives only the liquidus relations, that is, the temperature of completion of melting of various mixtures. The solidus relations, that is, the temperatures of beginning of melting, were not determinable in the dry way. Although not altogether conclusive, the relations found in the dry

way strongly suggest that KAlSi_3O_8 and $\text{NaAlSi}_3\text{O}_8$ form a complete series of solid solutions at high temperatures, of the type with a minimum melting temperature, complicated only by the incongruent melting of compositions rich in the potash component.

With the mixtures and the information available from previous work, a study of the behavior with water was undertaken. For this purpose, the Tuttle apparatus (last year's report) has proved very convenient, and in the detailed study of the crystalline phases the Norelco X-ray spectrometer with Geiger counter attachment has been of inestimable value. As was known from previous work, the recalcitrant behavior of alkali feldspar compositions examined in the dry way largely disappears in the presence of water vapor under pressure.

The homogeneous glasses of intermediate composition crystallized readily under hydrothermal conditions, and it was quickly established that the two components do indeed form an unbroken series of solid solutions or mixed crystals at high temperatures. Examination of the crystalline products in the X-ray spectrometer established this fact, and preliminary studies of optical properties indicate that there is a continuous change in these properties with composition. The X-ray powder spectra of the crystalline end members are very similar, but close examination reveals differences, one notable difference being the position of a rather prominent peak (maximum of intensity of X-ray reflection) on the spectrometer chart. The peak has a position corresponding to a 2θ value of about 22° for the soda end member and of about 21° for the potash end member. By reference to the single-crystal studies of W. H. Taylor this peak is identified as due to the $[\bar{2}01]$ reflection, and its position is, of course, determined by the $[\bar{2}01]$ spacing. Careful determinations of the position of

this peak were made for the end members and for 13 intermediate compositions by measuring the intensity of reflection as determined by the total count on the Geiger counter during a 5-minute period, at successive fixed positions spaced only 0.05° apart, all measurements being referred to a constant standard having a peak close to 23° . It was thus found that, for compositions crystallized at 900° and 300 atmospheres pressure of water vapor, the position of the peak changes continuously from end to end of the series, and that the variation with composition is sensibly linear. Since it was found that measurements on the same material could be duplicated within 0.02° and the total variation is about 1° , this must be regarded as a very satisfactory demonstration of the linear variation of the $[\bar{2}01]$ spacing in an unbroken series of solid solutions.

Conversely, by measuring the position of this peak, the composition of any feldspar of the series can be determined within an error of 2 per cent in proportions of the end members, which is at least as high accuracy as can be obtained in silicate chemical analysis of high grade.

Starting with a series of compositions crystallized as indicated above and proved to be homogeneous mixed crystals, we have proceeded to determine the solidus and liquidus relations at two isobars, 1000 atmospheres and 2000 atmospheres. It was established beyond question that at both isobars the series is of the type showing a minimum-melting composition, and at both pressures this composition is 70 per cent $\text{NaAlSi}_3\text{O}_8$. The ability to determine the composition of crystals by the position of the $[\bar{2}01]$ peak on the X-ray spectrometer was here of the greatest value, for in mixtures quenched from any temperature within their melting interval, and thus consisting of crystals and glass, it was still possible to determine the composition of

the crystals. This procedure, of course, locates a point on the solidus curve for that temperature. During progressive melting of the mixture with 70 per cent $\text{NaAlSi}_3\text{O}_8$ there was no change in the composition of the crystals, whereas during the progressive melting of a mixture on the potash side of this minimum the crystals moved still farther toward the potash side and in mixtures on the soda side the crystals moved toward the soda side. At the composition of this minimum-melting mixture and at the minimum temperature (840°) the liquid contains 7.7 per cent H_2O at 1000 atmospheres.

It is noteworthy that the minimum temperature at the 1000 atmospheres isobar lies 220° below the minimum temperature in the dry melts, but an additional 1000 atmospheres lowers the minimum only 70° farther, bringing it down to 770° . It may therefore be stated that alkali syenites under sufficient overburden to permit a pressure of 2000 atmospheres, say at a depth of about 5 miles in the earth, and given an adequate supply of water, will crystallize from the molten state at a temperature close to 770° . At greater depths and again with adequate water available, syenitic magma would crystallize at a still lower temperature, but not much lower; for, as has been seen, the effect of increased pressure rapidly diminishes. Not all mixtures have yet been studied, but as the work progresses from the minimum out toward the end members it is increasingly evident that the results will agree very closely with the early measurements at this Laboratory by Goranson on the melting of the end members at corresponding pressures of water vapor.

Studies of subsolidus relations have also been made, and here again the X-ray method of determining the composition of the crystals proved invaluable. It was found that, when crystallized at low tem-

peratures, the intermediate compositions gave two $[\bar{2}01]$ peaks, the one corresponding to a potash-rich feldspar and the other to a soda-rich feldspar, and the composition of each is determined by the position of its peak. There is, then, as had been deduced from the evidence of natural rocks, a failure of complete solid solution of the alkali feldspars at lower temperatures, and two feldspars are formed side by side. Moreover, the compositions of the two feldspars in equilibrium with each other at any temperature can be determined experimentally. The hiatus increases as the temperature falls. Much has already been accomplished in determining the width of the hiatus, but the work is very time-consuming, and determinations for some temperatures in the critical range are yet to be made. When they are completed it should be possible to determine rather closely the temperature of growth of any associated pair of alkali feldspars in natural rocks. It will be necessary only to determine the composition of the two feldspars.

One item of outstanding importance in the results of this work has not yet been mentioned. It is that the crystalline $\text{NaAlSi}_3\text{O}_8$ prepared in this work does not have properties corresponding to those ordinarily given for natural albite. The reason for this is not far to seek. The best source of crystals of feldspar approaching the albite end member is in pegmatites, where the feldspar is formed at relatively low temperatures. It is optically positive and has a large optic axial angle. The soda feldspar produced in the laboratory is optically negative with a small angle, and has notably lower refractive indices than the pegmatite albites. There are also quite marked differences in their X-ray patterns. Now there are soda feldspars in natural rocks that are optically negative with a small angle and low refractive indices.

They were studied long ago by F. Fouqué and were obtained by him from lava flows in which they occurred as phenocrysts. They are, accordingly, to be regarded as a high-temperature variety. To be sure, they were described by Fouqué as "anorthose" and some of them have a high potash content, but some approach albite reasonably closely (nearly 90 per cent $\text{NaAlSi}_3\text{O}_8$) and render it clear that there are in nature high-temperature albites. Our synthetic albite is the high-temperature variety; and, unfortunately, no matter how low a temperature or what combination of ingredients is used, only high albite has yet been produced, though it is certain that at the lower temperatures the high albite formed metastably. It is not an unusual experience with silicates to find great difficulty in producing low-temperature modifications in the laboratory, but usually some device is hit upon which turns the trick. The secret for albite has not yet been found.

It has been possible, however, to determine approximately the temperature of inversion by finding the lowest temperature at which the low-temperature modification (ordinary pegmatite albite such as that from Amelia County Court House in Virginia) can be transformed into the high-temperature variety. The change is very sluggish at any temperature, but can be brought about simply by heating the dry powdered mineral at 1080° for one week. This temperature is far above the inversion temperature, in spite of the slowness of transformation. With the aid of a flux of $\text{Na}_2\text{Si}_2\text{O}_6$ and water vapor at 1000 atmospheres, the change could be induced at 725° in a week, but not at 675° in two weeks. It is concluded, therefore, that the inversion temperature is approximately 700° .

The existence of this inversion in the sodic end member of the plagioclase series

necessitates an inversion in adjacent plagioclases at least. It has been confirmed that plagioclase with up to 30 per cent anorthite has high- and low-temperature modifications distinguished by their X-ray diffraction patterns. Beyond that range of composition, plagioclases suffer changes on heating which may or may not be of the same character. This is the work on plagioclases which was mentioned earlier and which is being further prosecuted. Clearly one cannot solve the problem of solid solution in the plagioclases by selecting natural plagioclases haphazard and determining their crystal structure by X-rays, as has been attempted. The crystals studied must be selected with reference to their manner of occurrence and probable temperature of formation, and the results must be correlated with measurements on synthetic feldspars grown at controlled temperatures.

SOLUBILITY OF QUARTZ IN STEAM

The investigations with water at high temperature and pressure may be considered to open up a new field of chemistry. The usual experimental conditions are such that the water is above its critical temperature and pressure and hence will ordinarily be called a vapor or gas, but in some of the work the water is under so high a pressure that its density becomes of the same order as that of liquid water at room temperature. Owing to its high density, the "gaseous" water may have a great solvent power for solids, and the often-discussed gas transport of solid material becomes a demonstrated fact. The current work on the solubility of quartz in steam furnishes an excellent example of this phenomenon.

Water under pressure is pumped into a heated pressure vessel containing crushed quartz. The pressure is held constant by

a regulator, and on entering the heated pressure vessel the water is changed to steam. This steam is slowly passed through the pressure vessel, cooled, collected, and weighed, and the amount of dissolved silica is determined by analysis. The rate of flow is controlled by a needle valve on the exit side of the apparatus, and rates ranging from less than 0.1 to 10 grams of water per minute have been used. Temperatures have ranged from 300° to 500° and pressures from 2000 to 15,000 pounds per square inch. The lower pressures are comparable with those used with modern high-pressure steam turbines, and the temperature range includes that of superheaters. This is of practical interest because the deposition of quartz and amorphous silica on the blades of high-pressure turbines leads to a serious decrease in efficiency and requires frequent shutdown for its removal.

The experimental results are rather striking. Even at the lower pressures and temperatures, the solubility of the solid, quartz, in the gas, steam, can easily be measured. At 400°, and still more at 500°, the solubility increases rapidly with the pressure. At 1000 atmospheres pressure (15,000 psi), the gas contains 0.25 per cent silica. This corresponds to a partial pressure of silica of 2.5 atmospheres—and silica is one of the least volatile of substances. Reaction takes place rapidly. Even when the rate of passage is such that the steam is in contact with quartz for less than 10 minutes, the vapor phase becomes three-quarters saturated, and 0.8 gram of silica is carried over per hour. At this easily attainable pressure, the solubility of silica in steam is ample to account for the formation of the quartz in pegmatite deposits.

THE SYSTEM $\text{H}_2\text{O}-\text{Na}_2\text{O}-\text{SiO}_2$

The first studies on the silicates of sodium and potassium in the presence of

water were published in 1914, and a detailed study of the system H_2O — K_2O — SiO_2 in 1917. The methods and apparatus used in that study are not suitable for H_2O — Na_2O — SiO_2 , because of the much greater pressures encountered and the resulting solubility of both Na_2O and SiO_2 in the gas. A successful technique was not developed until 1941, and progress was interrupted by the war.

In the report for 1940–1941 (Year Book No. 40) it was stated that sodium metasilicate and sodium disilicate have strongly retrograde solubilities, which fall practically to zero at the critical point of water, 374° and 212 atmospheres. This is the first intersection of the critical curve and the solubility curve; at the relatively low pressure that obtains here, the solubility in the gas is negligible. The second intersection of the critical curve must take place on the upper part of the solubility curve, a part of the curve that may be regarded as representing the lowering of the melting point by dissolved water. It is important to note that as the temperature is lowered the pressure required to hold the water in solution continuously increases. At 400° , 26° above the critical point of water, pressures on the isothermal saturation curve of sodium disilicate are greater than 1200 atmospheres, and at this pressure the solubility of solid in gas is important. Moreover, the gas does not dissolve Na_2O and SiO_2 in the same proportions that are present in the liquid; hence the gas and liquid must be regarded as ternary. The composition of gas, liquid, and, when present, crystalline phase must be determined.

In studying the system, it is found most convenient to operate at constant temperature and constant pressure. Most of the work has been at 400° , and the results for this isotherm are nearly ready for publication. Several series of isobars have been made. A silicate mixture of known com-

position is placed in a shallow platinum crucible, mounted on a pedestal in a pressure vessel (or bomb) of the metal Inconel. Stainless steel bombs were abandoned because when the Na_2O content of the gas was high it drilled holes through the 1-inch bottom overnight. The bomb with charge is placed in a furnace held at constant temperature, and water is slowly pumped in until the desired pressure is reached, the pressure then being held constant by an automatic regulator.

Usually after an overnight run the bomb is shut off from the pressure system and cooled, first in air, then in water, and opened. The contents are divided into three parts. Almost all the gas condenses to a liquid outside the crucible. This liquid is removed, weighed, and analyzed. In some experiments with high Na_2O content, it is necessary to dilute the condensed gas with water, otherwise it will partially solidify as NaOH before it can be removed from the bomb. The contents of the crucible consist of glass (representing a hardened liquid), or glass plus crystals, or crystals, plus some extra condensed gas which has reacted with the glass or crystals. This material is poured off and analyzed, and from this analysis the composition of the glass or the crystals or both, and the composition of the gas, the amount of this additional condensed gas, and the amount of material it has dissolved can be calculated.

GRAPHICAL REPRESENTATION WITH A VOLATILE COMPONENT

The method of study will be made clearer from a consideration of figure 1, which refers to a constant temperature and a constant pressure. The sides of the composition triangle H_2O — Na_2O — SiO_2 are omitted, except for a part of the side Na_2O — SiO_2 on which is located the composition of sodium disilicate (*Di*), Na_2O .

2SiO_2 . The lines 1-1, 2-2, and $Di-Di$ go from the H_2O apex to the indicated points on the side $\text{Na}_2\text{O}-\text{SiO}_2$; any mixture of Di and H_2O , for example, must lie on the line $Di-Di$. The dot-dash curves GG_1 and G_2G represent the compositions of gases in equilibrium with unsaturated liquids along the lines LL_1 , or L_2L , shown by solid lines. The dotted curve G_1G_2 shows the gaseous solubility of sodium disilicate. The curve $E_1L_1L_2E_2$ is the solubility curve of sodium

bomb, the gross composition of the mixture must be on the line from the H_2O apex to the composition of sodium disilicate, i.e., the line $Di-Di$. If the amount put in is less than that corresponding to the solubility of sodium disilicate in steam at this temperature and pressure, the composition will be on $Di-Di$ to the left of point a . At 700 atmospheres this is equivalent to about 0.7 gram, in the bomb used. When a little more is added, a clear glass

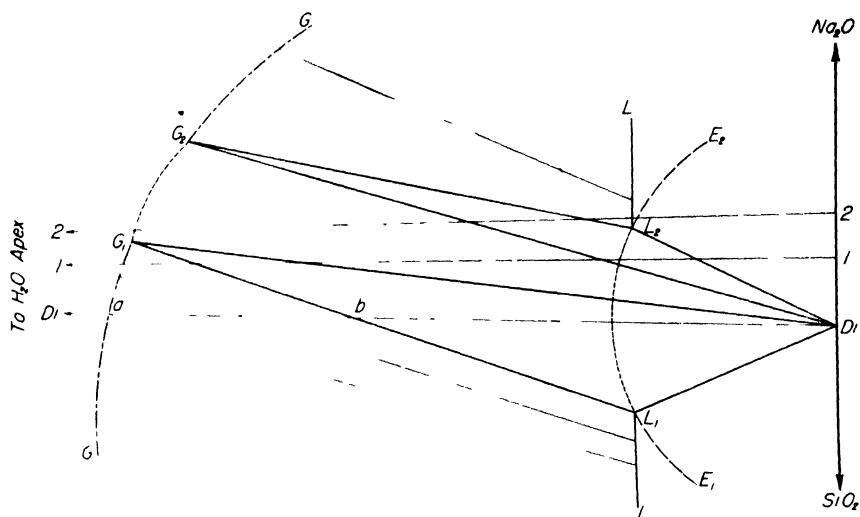


FIG. 1

disilicate in water; but, since at constant pressure and temperature there cannot be a series of solutions in equilibrium with gas and sodium disilicate, the curve is metastable except for the points L_1 and L_2 . The parts E_1L_1 and L_2E_2 represent solutions having vapor pressures less than that for which the diagram is made, and, therefore, unstable; and the part L_1L_2 , solutions having vapor pressures greater than that of the diagram. Only the liquids L_1 and L_2 can coexist in equilibrium with gas and solid at this pressure and temperature.

When sodium disilicate is placed in the

is found in the crucible, which is an unsaturated solution on the line LL_1 ; the corresponding gas compositions are indicated by tie lines. When the amount of disilicate corresponds to point b , crystals of disilicate begin to form. The composition of the gas is G_1 , that of the liquid L_1 , and these remain constant as long as there are present gas, liquid, and crystals. Addition of more disilicate results only in more crystalline disilicate; the composition will remain within the 3-phase triangle G_1-L_1-Di , all compositions are fixed, and only the proportions change.

If the original mixture is richer in SiO_2 than L_1 , disilicate can be formed only at lower pressures; and as the proportion of silica is increased, the pressure gets lower and lower until the boundary of the quartz field is reached, after which quartz becomes solid phase and the pressure increases rapidly. This disilicate-quartz boundary is at a low pressure, 250 atmospheres; the liquid contains 25 per cent H_2O , and the gas 99.7 per cent H_2O .

When a mixture of the composition of sodium disilicate is put into the bomb, the gas and liquid compositions, that is, the points G_1 and L_1 of the 3-phase triangle, depend on the pressure. At 700 atmospheres, G_1 corresponds to 95 per cent H_2O , 1.8 per cent Na_2O , and 3.2 per cent SiO_2 ; and L_1 to 21.5 per cent H_2O , 20.5 per cent Na_2O , and 58 per cent SiO_2 . The compound $\text{Na}_2\text{O} \cdot 2\text{SiO}_2$ contains 66 per cent SiO_2 . The solid dissolved in the gas contains 64 per cent SiO_2 , and the solid dissolved in the liquid 73.9 per cent SiO_2 , so that the disilicate has been divided between a gas phase containing a lesser ratio of SiO_2 and a liquid containing a greater ratio of SiO_2 .

At 1200 atmospheres pressure the corresponding values are: gas, 93.8 per cent H_2O , 2.8 per cent Na_2O , 3.4 per cent SiO_2 ; and liquid, 29 per cent H_2O , 22.7 per cent Na_2O , and 48.3 per cent SiO_2 . The solid in the gas now has 55.6 per cent SiO_2 , and the solid in the liquid 68 per cent SiO_2 . Even this higher pressure is not enough to liquefy sodium disilicate completely, although the percentage of silica in the dissolved liquid is now 68, not far from the 66 per cent of disilicate. It is a remarkable fact that at 374° the vapor pressure of the solution is about 212 atmospheres, whereas at only 26° higher it has increased to over 1200 atmospheres. If a solution of sodium disilicate in water is cooled from high

temperature, a pressure of over 1200 atmospheres will be developed as a result of the cooling and consequent crystallization. It may also be mentioned that gas and liquid are still far apart in composition, and that at a critical end point they must be identical.

Another significant fact is brought out by figure 1. The join D_1 - D_2 passes from the field of unsaturated gas into the field of gas plus unsaturated liquid, then into the 3-phase region. Starting with a mixture containing more Na_2O , along the line 1-1, the sequence of fields is the same, until it emerges into a field of gas plus crystalline disilicate. The dotted line G_1 - G_2 represents the gaseous solubility of crystalline disilicate, and mixtures along the line 2-2 pass directly into this region.

Further work at a little lower temperature will throw light on these and other interesting phenomena in a field that as yet has scarcely been investigated either theoretically or experimentally.

FILTER AUTOCLAVE

A solubility determination with the high-pressure-steam filter autoclave comprises four distinct phases: first, heating a reaction mixture to the desired temperature in the presence of steam at a predetermined steam pressure and then stirring it under these conditions of temperature and pressure until equilibrium is reached; second, filtering the reaction mixture with maintenance of the equilibrium temperature and pressure; third, cooling the filtrate to room temperature and atmospheric pressure without a change in its over-all chemical composition; fourth, analyzing the filtrate and identifying the solid phase.

A year ago it was reported that the first complete experiment had just been performed with this apparatus. Besides indicating the need for some mechanical

improvements in the apparatus, that experiment showed that the initial procedure for the third phase of the determination (cooling) was unsatisfactory. The problem of the change in water content of the filtrate during the cooling still remains, though a great many variations in cooling schedule have been tried. Solution of this problem was the major objective of the forty-two solubility determinations and four special experiments performed since the fall of 1948. It has been learned that liquid water enters the lower chamber of the autoclave and floods the crucible holding the filtrate. The source of the pressure difference that pushes the water into the lower chamber has not yet been discovered. Absorption of water by the cooling filtrate from the atmosphere of steam that surrounds it, which at first was supposed to be the only mechanism for the introduction of extraneous water, is so far overshadowed by flooding that it is not yet possible to tell whether it has taken place at all.

The search for the source of the extraneous water may be made by performing simulated solubility determinations in which no charge of silicate is present; and this has been done in some instances. In general, however, it was considered preferable to carry out complete solubility determinations. In this way experience was gained in the manipulation of the apparatus, and the various parts were given endurance tests. The value of this policy is attested by the fact that the number of unsuccessful solubility determinations has decreased steadily, as causes of failure have been discovered and overcome. The most troublesome one, which accounted for nine of the seventeen unsuccessful determinations, was leakage of nitrogen around the flange of the filter crucible during filtration. Although this condition prevented

the obtaining of a filtrate, it did not interfere with the acquisition of information applicable to the problem of the source of the extraneous water.

The leakage of nitrogen past the filter crucible has been prevented by several successive changes in design of the holder for the filter crucible. Other improvements made in the apparatus during the past year include a thrust bearing for the stirring shaft, a centering device for the autoclave (which permits alignment of the stirring shaft with the axis of the gear and thrust bearing), a keyway for mounting the stirrer on the shaft, and a turbo-compressor for forced cooling of both the autoclave and the steam boiler.

Another advantage of making complete solubility determinations before the cause of extraneous water has been eliminated is that some information has been gained about the attainment of equilibrium. Using as a criterion the K_2O content of the glass obtained by dehydration of the filtrate, the same result was obtained when KOH and quartz or glassy $K_2Si_2O_6$ and silica gel were used as starting materials instead of crystalline $K_2Si_2O_6$ and quartz. Several experiments in which the time of stirring under equilibrium conditions was reduced to 1 hour (normally it was 4 hours) indicated that this was not long enough for equilibrium to be reached.

The variation in K_2O content of the glass obtained from determinations performed under normal conditions was so small as to suggest that the limit of accuracy of a solubility determination performed with the filter autoclave (when the extraneous water is absent) will be that imposed by the analysis of the filtrate. Furthermore, the mean value of the K_2O content at 300° and 50 atmospheres pressure agrees well with that obtained by interpolation of previous data.

EXTREME HIGH PRESSURE

An important aspect of work with high pressure is the effect of pressure, in the absence of volatile components, on the melting and transition of minerals. Apparatus has been designed and constructed capable of simultaneously producing and maintaining pressures up to 15,000 atmospheres and temperatures up to 1400°. The immediate experiments planned involve temperatures between 500° and 800° and pressures up to 10,000 atmospheres. Data on the behavior of silicates in the range of conditions that can be produced by the ap-

paratus are essentially nonexistent. For this reason, the primary program involving the apparatus will be the determination of the change of melting point of minerals with pressure. From these data, thermodynamic properties can be calculated and correlated with the results obtained by other methods now being applied at the Laboratory. Having obtained this fundamental information, we shall be in a position to make an intelligent selection of other programs for high-pressure experimentation.

STATISTICAL PETROLOGY

Further work on application of statistical methods to petrology has been carried out, and a preliminary study of the relation between grain size, area of measurement, and sample variance has been completed. It turns out that the critical problem here is an instrumental one, since it will be necessary to establish a quantitative measure of grain size, if variances for rocks of different grain size are to be compared. The problem of measurement is very simple, for by substitution of a finer thread in the mechanical stage of the point counter almost any reasonable distance between points can be obtained, and the distance traversed is given by $(n-1)k$, where n is the number of points and k the distance between points. The best method of recording the measurement has not yet been determined. Several schemes are under consideration, and at present it appears that the best results would be obtained by substitution of a recording-tape adding machine for a counting cell.

Relations between ratios are often used in chemical petrology without full realization of the difficulties and ambiguities involved in passing from ratio correlations to inferences about relations between the

absolute values from which the ratios are formed. Usually it is these absolute values that are of primary concern. By application of a series of restrictions to the variables used in the Pearson general formula for index correlation, statements governing product-moment correlation between ratios in the special cases commonest in petrology are derived. Each special case is illustrated by one or more numerical examples drawn from the literature of petrology, and the general conclusion is that where interest centers on the absolute values, as is often the case, careless application of ratios is liable to be misleading and even their careful use is likely to yield ambiguous or uninterpretable results.

End-stage reactions in the crystallization of magma often take the form of pseudomorphous replacements, and the question as to whether these reactions occurred in a still homogeneous paste of solids and liquids, or after the separation of liquid residues from crystallized material, is one of recurring interest. Qualitative approaches to this problem have been largely unsatisfactory, since it is to be expected that fabric and habit will be very similar in late magmatic and early hydrothermal crystal-

lization. Provided that the reaction is truly pseudomorphous, however, a replacement occurring at about the same time in the entire mass would lead to a positive correlation between the amount of original mineral available to the reaction and the amount of replacement product formed, for the extent of replacement would be largely a function of the amount of original mineral available. If, on the other hand, the replacement occurs only after the magmatic residue has been strained away from some parts of the rock and concentrated in others, there will be no correlation between original mineral and replacement product. By means of the conventional part-whole correlation formula, it may be shown that under such circumstances there would be negative correlation between the amount of replacement product and the amount of original mineral surviving the reaction. On this basis it has been concluded that muscovite pseudomorphously replacing plagioclase in the Barre, Vermont, granite is late-magmatic rather than post-magmatic or hydrothermal. The argument is subject to certain

limitations which do not seriously hinder its practical application.

A detailed test has been made of the homogeneity of the well known granites from Westerly and Bradford, Rhode Island. Hand specimens were taken at each of the larger quarries in each granite; and from each hand specimen three thin sections were cut in such a fashion that variance analyses would provide information on variance attributable to differences between the two granites, between hand specimens of each granite, and within each hand specimen. This latter source of variation could be further analyzed into a location and an orientation factor. The end result is that differences between the two granites, though small, are readily detectable, that orientation and location effects within hand specimens of either granite are negligible, that small differences between hand specimens of the Westerly are detectable, but that the existence of such differences between hand specimens of the Bradford granite may not be inferred from the data.

STUDIES ON VOLCANIC PRODUCTS

In last year's report on the study of the rocks extruded at Santiaguito, the new volcanic cone halfway up the side of Santa María in Guatemala, it was stated that a study of the acid constituents of the emanations from the fumaroles would next be undertaken. The detailed studies have been concluded. In addition, considerable work was done on the incrustations that were found at and near the vents of the fumaroles.

Studies in the field revealed the fact that the fumaroles could be divided into two types which for the purposes of this report may be called A and B. At type A, steam at about 300° issued freely from open vents

and no free sulfur was visible. These fumaroles were on the eastern slope of Santiaguito and were situated about 300 feet above the floor of the crater developed on Santa María in 1902. At type B, about 700 feet above the crater floor, clouds of suffocating steam vapors issued from fine cracks. At a depth of about 12 inches below the surface, a layer of sulfur approximately 3 inches thick was found. The sulfur varied from solid crystalline form near the surface to liquid form increasing in degree of fluidity with depth. This mantle of sulfur, shot through with fine cracks, helped to maintain the rather surprisingly steep slope of nearly 50°.

ACID CONSTITUENTS OF THE EMANATIONS

Samples of condensed steam were collected from type A fumaroles in 1932 and 1939. Samples were collected from types A and B in 1940. Analysis showed that all contained appreciable amounts of the following constituents: hydrochloric acid, sulfuric acid, and sulfur dioxide. The concentrations of the condensate seem to vary from year to year. From 4 to 15 grams per liter of hydrochloric acid were found. In some cases the content of sulfuric acid was about the same as that of hydrochloric, but more frequently the latter dominated. In addition, the condensates were almost saturated with respect to sulfur dioxide. In type B the condensates were led into a solution of cadmium acetate, but, as was expected, no cadmium sulfide was precipitated, a fact which indicated the absence of hydrogen sulfide. The same procedure was followed at the fumarolic area type B, where the great deposits of free sulfur were found. A copious yellowish precipitate was formed, but analysis in the laboratory showed that it was free sulfur mixed with extremely minute amounts of selenium and tellurium. It is possible for H_2S and SO_2 to coexist at temperatures above about 300° (the steam temperature at both areas), but on cooling, they promptly react to form sulfur. This circumstance is considered to provide an explanation of the presence of sulfur at type B fumaroles. At the type A area the conditions are completely oxidizing, owing, we now believe, to aspiration of air into the edifice.

In addition to the main acid constituents mentioned above, hydriodic, hydrobromic, hydrofluoric, and boric acids were found in small but readily determinable amounts in the acid emanations from type A and type B. Even though the amounts of hydriodic and hydrobromic acid were small relative to the main acid constituents,

the amounts, about 3 milligrams of the former and from 2 to 20 milligrams per liter of the latter halogen acid, are not only significant but also surprising. It seemed desirable to ascertain whether or not other fumarolic areas exhibited a similar concentration of these acids. Water samples had been collected from the crater lake of Santa Ana in El Salvador and from the crater lake of Kawah Idjen in Java. The two lakes receive the volatile products from intensely active fumaroles located below and also above the lake level. Iodides and bromides in easily determinable amounts were found in the samples from both lakes. It appears that these halogen acids are probably more abundant in volcanic emanations than has heretofore been supposed.

INCRUSTATIONS

In general the particle size of many mineral constituents in the incrustations is so small that their identification has been exceedingly difficult and in some cases, up to the present impossible. As many of the mineral species as possible were identified by means of the microscope and X-ray analysis. Chemical analysis yielded considerable knowledge concerning the chemical environment. Additional mineral species were identified by the combination technique of breaking down each incrustation into groups by chemical methods and examining these by microscopic and X-ray methods.

As a result of study of the incrustations from fumaroles of type A by the technique just referred to, it appears that the chemical environment is so definitely an oxidizing one that only salts of the various bases contained in the andesitic rock are found in the stalactitic incrustations. Where these had been subjected to temperatures above 100° , only sulfates and partially decom-

posed rock minerals were found. In products subjected to lower temperature, chlorides of the various bases were abundant. It is interesting to note that where sulfates predominate they belong to the relatively water-insoluble group of complex aluminum sulfates; the more soluble alkaline salts are present only in subordinate amounts.

At fumaroles of type B, the mantle of sulfur, referred to above, had an orange color. Chemical analysis showed that the deep color was due to the presence of arsenic sulfide (As_2S_3), selenium, and tellurium. Microscopic examination showed that the sulfide was amorphous orpiment. Below the sulfur, a grayish-black indurated material was found. The microscope revealed the presence of opal (a hydrated form of SiO_2), sassolite (boric acid), and anhydrite ($CaSO_4$). It seemed obvious that the induration was due to the formation of opal and anhydrite. It is of interest to note that boric acid had previously been found in the condensates of the steam issuing from both fumarolic areas. The evidence seems clear that these products, which are readily volatile in this chemical environment at temperatures above 300° , have been brought up from the hotter lava below. As a matter of fact, they have an appreciable vapor pressure even at 300° , but have been held in place by the mantle of sulfur, the upper surface of which was at a much lower temperature. This gray-

black incrustation was further studied by the combination technique referred to above. It was shown that the dark color was due to about 1 per cent of exceedingly finely divided pyrite (FeS_2). In addition, between 5 and 10 per cent of the low-temperature form cristobolite (SiO_2) and a lesser amount of anatase, one of the crystalline forms of titanium oxide, were found. These minerals were formed by the interaction of the mineral constituents in the lava and the acid aqueous vapors given off by the hot lava below. The presence of the pyrite shows that at fumarole type B the chemical environment is definitely of a reducing nature. In view of the fact that the steam 5 inches below the surface has a temperature of about 300° , it is not likely that the chlorides could form; as a matter of fact, only an insignificant amount of the chloride ion was found in this incrustation.

Examination of a thin section of the indurated gray-black incrustations revealed the fact that the rock minerals had been completely altered, but the "ghosts" of the original minerals were plainly visible.

The information so far obtained from these chemical studies has an important bearing on rock alteration by means of the acid emanations and fluids that must exist on a large scale in many regions exposed to igneous activity. There is reason to believe that the results throw light on the earliest stages of such alteration.

THERMAL PROPERTIES OF MINERAL SUBSTANCES

Investigations of the thermal properties of mineral substances have been part of the recognized program of the Laboratory from the beginning, and upon the resumption of research in petrology at the close of the last war, greater emphasis was placed on this subject. Phase-equilibrium studies

show what crystalline substances are formed from silicate mixtures, the compositions of the liquids which can be in equilibrium with them, and the pertinent temperatures. But for the complete thermodynamic description of any system, it is necessary to know also the changes in

volume, and especially the heats of fusion and solution at all points on the solubility curves. Not until such knowledge is available can our results be applied to petrologic problems with full effectiveness.

In view of the scarcity of reliable thermal data on silicates, the diversity of silicate compounds, and the much greater geological importance of some than of others, a careful selection of the substances for study at this Laboratory has been made. Among the more important series of silicate minerals are the feldspars, pyroxenes, hornblendes, feldspathoids, micas, aluminum silicates both hydrous and anhydrous, garnets, melilites, and olivines, together with a galaxy of hydrous silicates and aluminosilicates. In order not to scatter efforts too widely over the field, it has been decided to concentrate at first on the feldspars and the chemically adjacent substances jadeite, nepheline-carnegieite, leucite, and kaliophilite. At present carefully "purified" natural minerals are being used, but since these are almost never pure chemical compounds, it will be necessary to study synthetic preparations as well.

Work on this project during the past year has consisted of purifying mineral samples, making heat-of-solution measurements, preparing for the measurement of specific heats, and synthesizing artificial preparations.

PREPARATION OF SAMPLES FOR HEATS OF SOLUTION

The Laboratory now has a series of excellent samples of feldspars, of some feldspathoids, and of the aluminosilicates sillimanite, andalusite, and kyanite, which have been purified by mineral separation methods and prepared in a very finely divided form suitable for solution in the hydrofluoric acid calorimeter. Analyses have been obtained for most of the samples.

THE SOLUTION CALORIMETER AND MEASUREMENTS OF THE HEATS OF SOLUTION IN HYDROFLUORIC ACID

Certain modifications have been made in the methods of measurement of the temperature rise in the gold calorimeter described in last year's report. In place of the Mueller bridge and type K potentiometer combination, a White double potentiometer has been installed as the measuring instrument, and the potential-drop method has been replaced by a method using a Wheatstone bridge with three fixed arms. The unbalance of the bridge is read on the potentiometer, the arrangement being in principle like that used in reading the pressure in the compressibility apparatus of this Laboratory. In order to utilize the sensitivity of the galvanometer to the fullest extent, the bridge has equal ratio arms for dividing the current of 2000 ohms each, and the resistance of the third arm and of the thermometer is of the order of 100 ohms. An important consideration in choosing the constants of the bridge is the current carried by the thermometer, which should be as small as possible in order that the heating effect of the thermometer be small. The third arm of the bridge is always kept at a lower resistance than the thermometer, so that the unbalanced emf will always be positive and will increase with the temperature of the calorimeter. When the temperature rise is less than 1° , the unbalanced emf is linear to better than one part in 10,000, with respect to the resistance change of the thermometer. With the setup as ordinarily used, the unbalanced emf is more than 500 microvolts per degree change in temperature, and the emf can be read to better than 0.1 microvolt, so that the error in temperature measurement does not need to be much greater than 0.0001° .

The electrical energy for calibration is

supplied to the calorimeter at a rate somewhat comparable with the rate of generation of heat by the dissolving sample. Heat-exchange correction is made using a computational procedure based on the Regnault-Pfaundler method. The calorimeter assembly is completely immersed in an oil bath kept at a constant temperature near 74.5° . The actual temperature variation is within 0.01° at present; and it is planned to improve this further, if it turns out that the accuracy of the results can be augmented by doing so. For the solution experiments, the calorimeter is filled with 819.1 grams of 20 per cent hydrofluoric acid, prepared by mixing distilled water with 48 per cent acid, of reagent grade.

The apparatus and methods were first tested by dissolving certain salts in water. These experiments gave results which were in good agreement with data found in the literature. A few orienting experiments with selected samples showed that the natural feldspars may be expected to dis-

solve in the acid without complications. Synthetic nepheline, on the other hand, though it dissolved rapidly in the initial decomposition, gave a post-precipitation of chiolite ($\text{Na}_6\text{Al}_3\text{F}_{14}$), the heating effect of which complicates the attainment of a constant heat-exchange rate after the solution is finished. There are still troublesome items of experimental procedure to be worked out.

Results have already been obtained for the heats of solution of quartz, albite, bytownite, anorthite, and adularia, which gave, respectively, 553, 564, 624, 646, and 527 calories per gram (rounded off to the nearest calorie). The rounded value obtained for quartz (99.95 per cent SiO_2 , 0.05 per cent impurities—mainly iron oxides) uncorrected for impurities, 553 calories per gram in 20 per cent acid, compares well with the final corrected value of Sahama and Torgeson, 549 in 20 per cent acid. Other values obtained in 20 per cent acid are: Mullert (1913) 498, Roth (1928) 517, and Troitsch (1932) 548.

DEEP SEISMIC PROSPECTING

Jointly with the Department of Terrestrial Magnetism, the Laboratory carried forward the investigation of the earth's crust by obtaining accurately timed records of the arrival of vibrations from charges of explosives set off at distances up to several

hundred kilometers. Further information concerning the thickness and nature of the crustal layers has been obtained. Details of the results are to be found in the report from that Department.

The following is a list of the papers published during the report year in technical journals. In addition there are several papers that have been prepared and are awaiting publication. These are: F. Chayes, "On a distinction between late-magmatic and post-magmatic replacement reactions"; G. L. Davis and H. H. Hess, "Radium content of ultramafic igneous rocks. II. Geological and chemical impli-

cations"; G. L. Davis, "Radium content of ultramafic igneous rocks. III. Meteorites"; F. C. Kracek, "Phase transformations in one-component silicate systems"; J. F. Schairer, "Phase transformations in poly-component silicate systems"; A. H. Stone, "On supersonic flow past a slightly yawing cone. II"; and O. F. Tuttle, "The variable inversion temperature of quartz as a possible geologic thermometer."

SUMMARY OF PUBLISHED WORK

- (1104) A simple point counter for thin-section analysis. F. Chayes. *Amer. Mineralogist*, vol. 34, pp. 1-11 (1949).

A manually operated point counter for thin-section analysis is described. The machine is sturdy, inexpensive, and easily operated. Its precision has been tested by analyzing in duplicate 47 thin sections of rocks and computing the analytical error, or standard deviation of a single analysis, from the observed variance of the differences. The error distribution is effectively binomial, and the precision of the instrument is somewhat better than that of the Wentworth-Hunt and Hurlbut integrators. Average operating speed is about four times that of the Wentworth-Hunt and twice that of the Hurlbut machine.

- (1105) A new hydrothermal quenching apparatus. O. F. Tuttle. *Amer. Jour. Sci.*, vol. 246, pp. 628-635 (1948).

A simple apparatus has been developed for the study of equilibrium relations at high temperatures and pressures in mineral systems including volatile components. Investigations have been carried to pressures of 30,000 pounds per square inch (approximately 4.5 miles depth) at temperatures up to 900° C. Results on the system $K_2O-Al_2O_3-SiO_2-H_2O$ show that a water pressure of 15,000 psi lowers the liquidus about 100° in the orthoclase field. In compositions approaching the quartz-orthoclase join, a pressure of 30,000 psi gave relatively insignificant additional lowering.

- (1106) The radium content of varved clay and a possible age of the Hartford, Connecticut, deposits. William D. Urry. *Amer. Jour. Sci.*, vol. 246, pp. 689-700 (1948)

The radium content of the summer and winter portions of the varves in the clay deposits at Hartford, Connecticut, varies rhythmically. When the radium contents of the summer and of the winter portions are plotted against time as measured by the varve count, the curves exhibit slopes of opposite sign. The total radium content of any varve, how-

ever, is practically constant. These phenomena may be due to a disturbance of the radioactive equilibrium, but this hypothesis, though plausible, is far from proved. A greater concentration of uranium relative to ionium in the winter clay than in the summer clay would explain these phenomena. Such a disturbance of the equilibrium provides a means of determining the age of the deposits. On this basis, there is derived a tentative figure for the age of the Hartford clay (varve 3700) of 18,000 years. The hypothesis of a disturbance of radioactive equilibrium is supported by the fact that the analyses of the summer and winter curves, which are completely independent, give very nearly the same age.

- (1107) Radioactivity of ocean sediments. VI. Concentrations of the radioelements in marine sediments of the southern hemisphere. William D. Urry. *Amer. Jour. Sci.*, vol. 247, pp. 257-275 (1949).

It has been reported in previous publications of this series that the mode of variation of the radium concentration below the ocean bottom affords a method of determining time in ocean sediments. Hitherto, these researches were confined to the northern hemisphere. Similar studies in the southern hemisphere, combined with the necessary geological and biological investigations, should provide an answer to the question of the contemporaneity of glaciation in the northern and southern hemispheres. Measurements of the radium content as a function of depth in the sediment are presented here for ocean-bottom cores obtained by the U. S. Navy Antarctic Expedition of 1946-1947.

- (1109) Radioactivity of ocean sediments. VII. Rate of deposition of deep-sea sediments. William D. Urry. *Jour. Marine Research*, Sverdrup Sixtieth Anniversary, vol. 7, no. 3, pp. 618-634 (1948).

A study of the variation of the radium content during the period of re-establishment of radioactive equilibrium in the buried deposits of deep-sea sediments provides a method of

dating the record of past events in the ocean bottom. The results of such studies can be readily applied to determinations of the rate of deposition provided that knowledge of the distortion involved in obtaining core samples of the deep-sea sediments is available.

Application of the method of discerning rates of deposition is not limited, as was the application of earlier methods, to sediments deposited during postglacial time; it is possible to study the variation of the rate of deposition in the past as far back as the method of dating is applicable, i.e., for about half a million years. Rates of deposition as a function of time are reported here for red clay, globigerina ooze, foraminiferal marl, glacial marine deposit, and calcareous blue mud from areas extending from the Antarctic Ocean to the North Atlantic.

Outstanding features of these determinations are as follows: Deposition of practically all the sediments is more rapid at present than during the past half million years. The repeated climatological changes of the ice age did not have a particularly noticeable effect on the rate of deposition in general. Only during the long middle interglacial stage did the rates tend to be somewhat higher than the low rates generally prevailing in the past half million years. The lowest rates of deposition are associated with the last glacial stage and the early period of the middle interglacial stage or possibly the end of the second glacial stage. Locally, there are often interesting short-period changes in the rate of deposition which appear to be caused by climatological changes.

However, the amount of detail in an analysis of the rates of deposition varies greatly: in cores of equal length, far more detail can be obtained in one where the sediment was deposited in a hundred thousand years than in one where the sediment required a million years for deposition.

Average rates of deposition, in so far as they are comparable, are in good agreement with previous estimates by the *stratigraphic* and *supply* methods.

(1110) On ratio correlation in petrography. F. Chayes. *Jour. Geol.*, vol. 57, no. 3, pp. 239-254 (1949).

The same ratio correlation may be generated by many different combinations of relations between absolute measures, but a single set of absolute-measure statistics leads to one, and only one, correlation between any particular set of ratios formed from these absolute measures. The passage from ratio correlation to inference about relations between absolute measures is ambiguous at best and often misleading.

Algebraic statements exhibiting ratio correlation as a function of absolute-measure statistics are offered for types of ratios commonly used in petrography. These statements are all derived from Pearson's general formula for index correlation. They yield good approximations only if the fraction s/\bar{x} for each absolute measure is suitably small.

Several practical examples drawn from petrographic literature are described. In most of these cases the ratios seem to have been used either to order the data or in the hope that they would throw some light on relations between absolute measures. The results are shown to be on the whole indecisive and ambiguous and in a few cases decidedly misleading.

The formation of ratios should be confined to those problems in which hypotheses being tested deal with ratios. Absolute measures are always preferable when large numbers of observations must be recorded without benefit of satisfactory hypothesis. Ratios can always be drawn from tables of absolute measures; frequently, absolute measures cannot be reclaimed from tables of ratios.

(1111) The system $\text{MgO}-\text{SiO}_2-\text{H}_2\text{O}$. N. L. Bowen and O. F. Tuttle. *Bull. Geol. Soc. Amer.*, vol. 60, pp. 439-460 (1949).

Equilibrium in the system $\text{MgO}-\text{SiO}_2-\text{H}_2\text{O}$ has been determined at temperatures up to 1000°C . and at maximum pressures of water vapor varying from 15,000 pounds per square inch at this maximum temperature to 30,000 psi in the range $900^\circ-600^\circ$, and 40,000

psi in the range 600°–300°. Thus were fixed the univariant pressure-temperature curves of the following five reactions: I, serpentine + brucite \rightleftharpoons forsterite + vapor; II, serpentine \rightleftharpoons forsterite + talc + vapor; III, forsterite + talc \rightleftharpoons enstatite + vapor; IV, talc \rightleftharpoons enstatite + quartz + vapor; and V, brucite \rightleftharpoons periclase + vapor. Pure magnesian serpentine has a maximum temperature of existence at approximately 500°, varying only about 10° in the whole range of pressure, 2000 to 40,000 psi. Forsterite is stable in contact with water vapor down to a temperature of about 430° (at 15,000 psi). Only below that temperature is it transformed into serpentine and brucite. Iron-bearing olivines are stable in contact with water vapor down to still lower temperatures.

No liquid is formed in any composition of the system throughout the range of temperatures and pressures at which experiments were conducted, a condition which remains unchanged when the mixtures have upwards of 7 per cent FeO.

There is consequently no likelihood that any magma can exist that can be called a serpentine magma and certainly no possibility of its existence below 1000°. There seems no escape from the conclusion that ultramafics can be intruded only in the solid state.

- (1112) Some examples of the application of thermochemistry to petrology. Th. G. Sahama and D. R. Torgeson. *Jour. Geol.*, vol. 57, no. 3, pp. 255–262 (1949).

A brief summary is presented of measurements of heats of solution of minerals belonging to the forsterite-fayalite and to the enstatite-orthoferrosilite series and of artificial ilmenite and geikielite.

In the olivine and orthopyroxene series, the heat of solution of HF is found to be a linear function of the Mg : Fe ratio, indicating perfect isomorphism between the corresponding end members. The importance and possibilities of applying calorimetry to the study of isomorphism are emphasized. On the basis of the calorimetric data available for the minerals in question, the heat and free energy

are given for the reaction: olivine + quartz \rightarrow 2 pyroxene. The difference in the stabilities of MgSiO_3 and FeSiO_3 is illustrated.

The stability reaction of ilmenite and geikielite in the presence of olivine or orthopyroxene is calculated from the calorimetric data. The influence of the entropy of mixing isomorphous minerals upon the stability relation is emphasized.

- (1113) Significance of radioactivity in geophysics—thermal history of the earth. William D. Urry. *Trans. Amer. Geophys. Union*, vol. 30, pp. 171–180 (1949).

It appears that the effects on the earth's thermal history of the exponential decay of the sources of atomic (radioactive) heat within the earth are such that the upper crust was heating in its early history and that subsequent cooling has been more nearly linear than had been supposed. In the deeper parts of the crust and below, the thermal history has been complex, with simultaneous heating at one depth and cooling at another depth. Temperatures in the past beneath a Pacific-type ocean have not varied in the same manner.

- (1114) Melting relations of chalcocite. Einar Jensen. *Norske Videnskaps-Akademi, Oslo, Mat.-Naturv. Klasse, No. 6* (1947).

A study of the melting relations of chalcocite by the method of differential thermal analysis shows a maximum melting temperature of 1129° C. for the composition $\text{Cu}_{1.089}\text{S}$, which melts sharply. Mattes containing more or less sulfur than this, including pure Cu_2S , melt lower and over a temperature interval—pure Cu_2S from 1107° to 1127°. The limit of solubility of liquid copper in liquid chalcocite is found at a total composition of 80.21 per cent copper at 1105°. The solubility of copper in solid chalcocite is too small to be observed at 1105° and 1127°. The limit of solubility of sulfur in chalcocite could not be observed. No transformations in the solid state could be observed between 404° and melting temperatures in the composition range 77 to 82 per cent copper.

- (1115) The system silver sulfide—antimony trisulfide. Einar Jensen. *Norske Videnskaps-Akademi, Oslo, Mat.-Naturv. Klasse*, No. 2 (1947).

Nine minerals are known with a composition within this binary system. Previous thermal studies of the phase relations by Pelabon, Jaeger and van Klooster, and Konno indicate the existence at the melting point of the intermediate compounds $\text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3$ and $3\text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3$ only, corresponding to the minerals miargyrite and pyrrargyrite, respectively. The present study of the phase relations was performed by differential thermal analysis on pure samples of exact composition, heated in sealed Pyrex tubes provided with thermocouple wells. The results indicate that the compound $\text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3$ has a polymorphous transition at some temperature below 380°C . and melts congruently at 518.7° . The compound $3\text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3$ melts at 485.8° . As the proportion of Ag_2S in the preparations increases, the liquidus curve first falls from 554° , the melting point of Sb_2S_3 , to a eutectic with $\text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3$ at 462° , 22 per cent Ag_2S , then rises to the melting point of this compound, and again falls to a second eutectic, between $\text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3$ and $3\text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3$, at 464° , 59 per cent Ag_2S . The melting curve of $3\text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3$ rises from this eutectic and after passing through its maximum descends to a third eutectic at 470° , 77 per cent Ag_2S . From this point the curve remains almost horizontal to the neighborhood of 80 per cent Ag_2S , from which point it finally rises to the melting point of Ag_2S at 837.0° . The author suggests that the nearly horizontal portion of the melting curve may be the result of intrusion into the binary system of the liquidus surface of some ternary compound in the system $\text{Ag}—\text{Sb}—\text{S}$. The transition in $\text{Ag}_2\text{S} \cdot \text{Sb}_2\text{S}_3$, mentioned above, was found to begin, on heating, at temperatures as low as 344° , and to end at 370 – 380° . On cooling there was no reverse transition; on reheating after some weeks at room temperature a negative heat effect shows up near 207° . This leads to the conclusion

that the equilibrium transition temperature lies between 207° and 344° (359° in the pure compound).

- (1116) Pressure-volume-temperature relations in solutions. VIII. The behavior of some solutions of electrolytes in water. R. E. Gibson and O. H. Loeffler. *Ann. New York Acad. Sci.*, vol. 51, pp. 727–752 (1949).

This paper presents the results of measurements of specific volumes of solutions of sodium bromide and sodium chloride over a wide range of pressure, temperature, and concentration. From these data various thermodynamic properties of the solutions, namely, the volume change on mixing, the pressure-temperature coefficient, the energy-volume coefficient, and the change in specific heat with volume at constant temperature, are calculated; the data are presented in detail in the form of tables and curves.

The effects of pressure, temperature, and concentration on the various thermodynamic properties of solutions discussed in this paper are all in qualitative agreement with the current theories of the molecular distribution in water. A comparison of the thermodynamic properties of sodium bromide in water and in glycol indicates that the contractions on mixing, the thermal expansions, and the energy-volume coefficients of the aqueous solutions at the lower temperatures are largely determined by the effects of short-range forces, and that the effects of ion-molecule interactions are only secondary. At higher temperatures the effects of short-range forces have a decreasing influence on these volumetric properties. Indeed, there is good reason to believe that above 150°C , the ion-molecule interactions and other long-range forces will play the significant part in determining the volumetric behavior of aqueous solutions and that simple regularities will be revealed that are masked at the temperatures where most of our information is now available.

- (1120) Annual report for 1948–1949.

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DEPARTMENT OF TERRESTRIAL MAGNETISM

Washington, District of Columbia

MERLE A. TUVE, *Director*

Three years ago, beginning afresh on "significant research toward philosophical goals" after the interruptions of World War II, the staff of the Department stated three simple problems in geophysics which remained conspicuously unsolved, despite two generations of study on "the magnetic and electric condition of the earth and its atmosphere." These were as follows: The causes, inside the earth, of the earth's magnetic field are unknown; the mechanism which replenishes the earth's measured electric charge is not identified; mechanisms which give rise to particles of cosmic-ray energies are not yet recognized. The staff considered that these three basic puzzles might well serve as landmarks for orienting the geophysics program.

It is surprising to be able to report that the second of these questions, relating to the maintenance of the earth's electric charge, has been resolved by measurements in the clear air high above thunderstorms. One must also recall that unexpected evidence for a close relation of cosmic rays to our sun and to other stars was found in 1946, as reported two years ago, when cosmic-ray increases were discovered to occur at the times when large solar flares were in progress. All three of these problems in 1946 seemed basic in our thinking, yet probably beyond the reach of direct

investigation. It is encouraging indeed to find that formulation of a central problem in the simplest and most direct fashion can, with good fortune, be followed by significant new knowledge. The measurements above thunderstorms, carried out with the help of the U. S. Air Forces, are described below.

It remains to be seen whether direct knowledge can be obtained as to the causes, inside the earth, of the earth's magnetic field. No direct approach to this puzzle has yet presented itself, but new evidence, brought out in the course of a study of prehistoric changes in the compass direction, has instead opened up surprising questions relating to the possibility of great movements of the earth's crust with respect to the core and geographic poles during ancient geological epochs. This unexpected finding has been brought to light through studies of the residual magnetization of rocks.

In the laboratory phase of the Department's work, a steady development of the biophysics program is a strong indication that men trained in the physical sciences find ample challenge in the organized behavior of living matter, can formulate problems, and can obtain answers of interest and significance in this field.

EXPERIMENTAL GEOPHYSICS

THE EARTH'S CRUST

PALEOMAGNETISM

In the last annual report, there was extensive discussion of a program for investigation of the residual magnetism of

the sedimentary rocks in the earth's crust. This program was initiated with the hope that the results might provide a detailed history of the changes of the earth's magnetic field extending back millions of years in geologic time.

Our investigations have demonstrated that when sedimentary rocks are laid down in tranquil water they may acquire a direction of magnetization as the result of the statistical alignment of magnetized grains parallel to the earth's field. Therefore, a record of the past directions of the earth's magnetic field is found preserved in some sedimentary rocks. Recent tests here have demonstrated that sediments may retain a direction of magnetization without change for as long as 200 million years, and it now appears that it should be possible to trace far back in time the history of the changes in direction of the earth's magnetic field.

Rock magnetism reconnaissance expedition of 1948. The Department's studies of the magnetization of crustal materials have heretofore been confined to relatively young unconsolidated sediments from New England glacial deposits and from ocean cores. The results of these studies indicated that for the past million years the earth's magnetic field has had much the same orientation that it has today, and that its strength has remained approximately constant. In an effort to extend our knowledge of the changes of the earth's magnetic field farther back in geologic time, a three-month expedition to the flat-lying sedimentary deposits of the western United States was carried out during the summer of 1948. Samples were taken at eight sites scattered from Colorado northwestward to Washington and eastward into Wyoming and South Dakota. The age of the rocks measured ranged from approximately 10 to 100 million years. Because many rocks are not perceptibly magnetized, and because of difficulties with the techniques of preparing samples, only 96 separate observations of magnetic polarizations could be made. The results are summarized in figures 1 and 2, in which the directions of the horizontal com-

ponent and of the inclination of the rock magnetizations are indicated. The limited number of sites and samplings makes it unwise to draw extensive conclusions from the data, but the pronounced maxima in the two graphs suggest that for the past 100 million years, roughly, the earth's magnetic axis has remained centered, on the average, on the geographic axis. This interesting possibility is consistent with various different theories of the origin of the earth's magnetic field, and therefore cannot be advanced as an argument favoring any one of them.

Stability of magnetization. Workers in the field of rock magnetism have long recognized the necessity for demonstrating that rocks are capable of retaining their initial directions of magnetization from the time of their origin to the present. Definitive results on this question were obtained in 1948 from experiments which satisfactorily take into account long periods of time as a factor in the behavior of magnetization. This factor was treated by utilizing in the magnetism studies changes in geologic structure which took place millions of years ago. It is possible in many localities to locate rock exposures where sedimentary beds were long ago squeezed into contorted arches by mountain-building forces. Observations in these squeezed and folded beds have yielded knowledge of the permanence of the directions of magnetization.

One particular series of observations on Silurian rocks (350 million years old) that are well exposed at Hancock and Pinto, Maryland, is of special interest. In one of the folded beds, shown in plate 1, it was possible to obtain 20 suitably spaced measurements of the directions of magnetization. The directions were found to vary systematically throughout the fold in a manner that has an intimate relation to the attitude, or position in space, of each

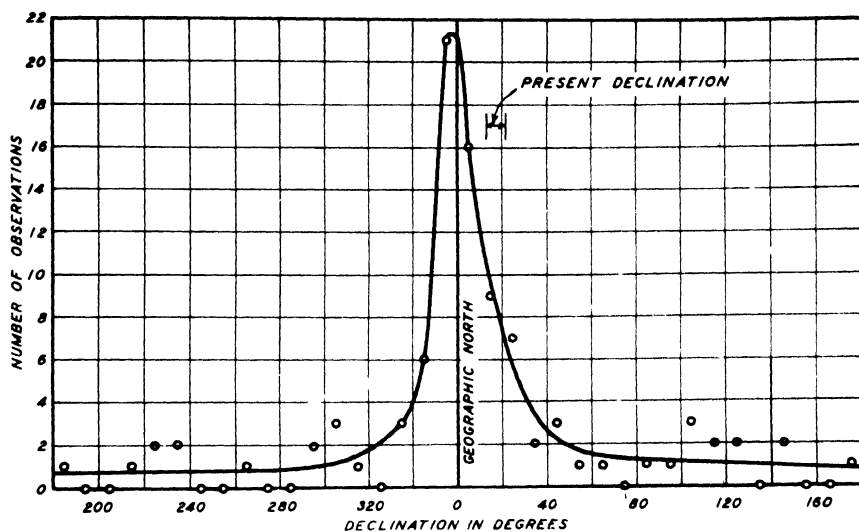


FIG. 1. Frequency distribution of declination measurements on rock samples

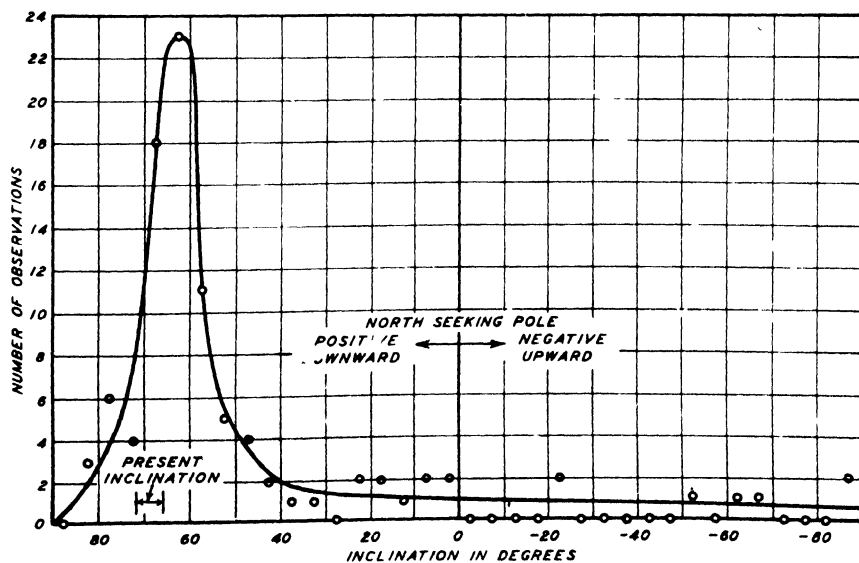


FIG. 2. Frequency distribution of inclination measurements on rock samples

part of the bed where an observation was made. The closeness of this relation is clearly brought out when a graphic reconstruction is made to restore the bed to its initial flat condition. Although the directions of magnetization in the fold are fanned out, and show differences in direction of as much as 127° , when the bed is made flat by a graphical transformation the magnetizations are all brought into general alignment so that these differences are usually less than 15° . This intimate relation of the directions of magnetization to the attitude of the bed is evidence that the bed was uniformly magnetized initially, that as it was folded it was merely flexed into its present configuration without yielding to shearing forces, and that since the time of the folding, 200 million years ago, the magnetizations at each point throughout the fold have not changed their initial directions.

There is still some question whether the reconstructed direction of magnetization of the fold at Pinto can be taken as a measure of the direction of the earth's field in Silurian time. The beds were laid down perhaps 150 million years before they were folded, and in that interval of time, long after deposition, they could have acquired their present reconstructed direction of magnetization. Further studies are needed to settle this point. There is evidence, however, that these beds acquired their magnetization, not in a field of a very local nature such as might surround a bolt of lightning or an intensely magnetized ore body, but in a field that was uniform over a large area, because beds of the same age at Hancock, 50 miles away, show the same reconstructed direction of magnetization. The surprising thing about the reconstructed direction of polarization is that the south-seeking pole is downward, contrary to the polarization of the present-day magnetic field, in which the north-seeking

pole is downward in the earth's northern hemisphere.

Along with this demonstration of stability, it has been possible to throw some light on the instability of samples stored in the laboratory. Some workers have considered that if a sample changes its direction of magnetization in the laboratory, it is inherently unstable and hence cannot be relied upon for deducing past directions of the earth's field. In the present work it has been observed that samples from the Silurian, as well as some of the younger samples from the western United States, also change when stored in the laboratory, and it has been possible to show that these changes are greatly accelerated by almost insignificant alternating magnetic fields. Stray fields of this kind exist in every laboratory building, but not in primitive geological areas. The mechanism by which such changes take place is not yet clear and requires further study.

New program. A new phase of the program of investigation now centers on determining in detail the regional character of the magnetization of Silurian rocks. It has been an astonishing experience to find that at two sites in the neighborhood of Washington there are rocks having their south-seeking poles directed downward. If it can be demonstrated that this anomalous magnetization prevails over large areas in a particular span of geologic time, a potent new tool will be at hand for studying some of the problems of earth physics.

Work on this phase of the program was initiated, under a special grant from the Carnegie Corporation of New York, by a reconnaissance study of Silurian rocks at Birmingham, Alabama, and the same anomalous magnetizations that were found at the Maryland sites were noted in a restricted series of beds. Below these beds two other major changes in magnetization of the Silurian rocks at Birmingham were



Folded Rose Hill formation Pinto Maryland

noted. Adequate fossils for precise dating were lacking at this site, and thus there is some question whether the rocks are strictly contemporaneous with those from Maryland.

Also, as part of the new work, an extensive sampling of the Hancock Silurian beds was made in the last few days of the report year. The data obtained indicate that in the 500 feet of deposition exposed at this site the anomalously magnetized beds occupy a middle section of approximately 200 feet, there being 100 feet above and 200 below which are magnetized much more nearly in the direction of the earth's present field.

Instrumentation. Experience with many different sediments has made clear the necessity for two basic improvements in instrumentation: greater sensitivity in the measuring apparatus, and a versatile core-drilling rig that will make it possible to sample exposures where the rocks are so massive that small oriented slabs cannot be removed easily by hand. A new remanent magnetometer has been built and shows promise of giving greater sensitivity and ease in making measurements. Since it contains many standard electronic parts, construction is relatively simple. A lightweight drilling rig is also ready for field use and, it is hoped, will make possible the study of many exposures that heretofore have had to be abandoned.

SEISMIC INVESTIGATIONS

As reported last year, a series of seismic observations from Solomons, Maryland, northwest to a distance of 300 km was carried out. When the times of the first arrived pulses were plotted as a function of their distance, it was seen that these times do not fall on a straight line, but that, beyond 130 km, each succeeding group of points appears to represent a wave

of greater velocity than that of the preceding set of points. This indicates an increase of velocity with depth, and it was possible to deduce (with the auxiliary confirmation of some arrivals later than the first or second ones) several different velocities and a multiple-layered structure down to the Mohorovičić discontinuity at a depth of some 40 km. The velocity of compressional waves in the material near the surface appeared to be 6.1 km/sec, while that below the Mohorovičić discontinuity was 8.1 km/sec.

One of the more interesting aspects of the data was a group of strong second arrivals, observed at distances of from 90 to 120 km, which came in about 2 seconds after the first arrivals. The best explanation at hand, based on the earth model deduced from all the other data, was that this arrival could be a shear-type wave (S) generated from the partial conversion of a compressional-type wave (P) at the interface between the bottom of the upper layer of rock and the top of the first intermediate layer at a depth of 10 km, the wave being called P10S. It was necessary to collect more observations in order to make sure that this peculiar wave was not a chance interference; observations were obtained at intervals of 5 km in this intensity region. The arrivals were as clearly discernible as those previously observed and seemed to furnish convincing evidence that the phase was real and due rather to the earth structure than to a fortuitous interference. This wave, if it could be proved a converted P-S wave as interpreted, might be an exceedingly useful one, because a generated S wave must rise at a steep angle from the interface, and from the difference in the arrival between it and the first arrival, the depth of the layer could be deduced with considerable precision. Thus the desired type of exploring probe would have been attained. The validity of this interpreta-

tion, was tested, however, using a new method of recording the seismic waves, and these tests showed during the past report year that this conspicuous arrival is in reality a compressional wave (P wave), not a shear wave (S wave), and hence is not a ProS and will not serve as the desired "probe."

It thus became necessary to reconsider the data. In the meantime investigations had been made on the amplitude of the seismic waves due to the routine calibration of the amplifiers at each observation point, with a single electric pulse generator. From these data it was found that the amplitude of this second arrival rose somewhat abruptly and then dropped off with distance. The observations of the abrupt rise were somewhat hampered by the existence of unconsolidated sediments ending at about 80 km from the source of explosion and by the presence of a city (Washington, D. C.)—a locality of vigorous seismic unrest—at the distance of interest. The rather abrupt appearance of this wave and its P-wave characteristics seemed to indicate that it was a critical reflection as first predicted by Knott in 1899. Trial solutions showed that if the velocity below the Mohorovičić discontinuity was taken as 8.1 km/sec (as measured), and a depth of some 33 km and a velocity of 7.1 km/sec just above the discontinuity were assumed, good agreement was obtained with the data, which, though consistent in themselves, need further checking with shots so placed that the seismic waves may travel in directions other than the ones normally observed. It is hoped that, with the aid of the Navy, the Department may establish its own "quarry." For this a water-filled unused stone quarry, far from any habitation, is needed. A typical geophysical problem is here presented: the interpretation of a set of data, with the open question of how

closely this agrees with the actual properties of the earth. More measurements are necessary.

In the latter part of July 1948 the Department was notified that the Tennessee Valley Authority was about to set off 500,000 pounds of explosive for the purpose of obtaining crushed rock for a large dam on the South Holston River at a site 5 miles from Bristol, Tennessee. This turned out to be the first of three large shots. The other two were of 1,500,000 pounds and 800,000 pounds, fired in October 1948 and February 1949, respectively. They furnished an opportunity to obtain precision seismographic observations out to 1500 km. Excellent seismograms were obtained, roughly in two lines radiating northeast to Maine and northwest to Wisconsin from the dam: to the northeast, 15 seismograms from 250 to 1200 km, and to the northwest, 9 seismograms from 90 to 800 km. One other seismogram was obtained by the New Mexico School of Mines at a distance of 1500 km west. The success of these measurements was due in large part to the co-operation of the Tennessee Valley Authority. Some of the observations were made by colleagues at Columbia, and several stations were occupied by the Office of Naval Research.

The first result obtained from these observations was the measurement of the travel of the compressional (P) wave through the ultrabasic rock just under the Mohorovičić discontinuity. This ray of the wave first arriving at distant observation points takes a downward path from the explosion through the intermediate layers. It is then refracted at the Mohorovičić discontinuity and extends almost parallel to this level and not far below it, and near the observation point it is refracted once more into the intermediate layer and proceeds to the surface. If the crust were uniform and the rock just under it homogene-

ous, then the arrival times at the various stations would lie along a straight line in a time-distance plot. But the actual observations, accurate to 0.02 second, diverged as much as ± 1 second from the straight line of the mean travel time. This indicated a nonuniformity which could be due to differences in crustal velocities, in crustal structure, in total crustal thickness, or in the propagation velocity under the Mohorovičić discontinuity. For the final shot the stations were distributed from 90 km out to 900 km, and they gave evidence of a critical reflection similar to that which was observed from the shots from Solomons. The indicated depth is greater, however, under the region northwest from South Holston. The tentative conclusion is that the data indicate among other things a greater depth of the Mohorovičić discontinuity under the Appalachian Mountains, particularly northeast and northwest of South Holston at distances out to 500 km. This cannot be regarded as a definite result, however, until more work has been done on the upper crustal layers near South Holston.

THE EARTH'S ATMOSPHERE

THE EARTH'S ELECTRIC FIELD

Thunderstorm Investigation

During the thunderstorm season of 1947, four airplane flights were made over thunderstorms, but records from only three of these were satisfactory for analysis. These results, as given in last year's report, were regarded as provisional. After the close of the 1947 season, instruments were improved and the airplane was stripped of armament, so that higher altitudes could be reached and maintained.

During the 1948 thunderstorm season, again with the co-operation of the U. S. Air Forces, successful flights were made

during July, August, and September from the Clinton County Air Base, Wilmington, Ohio, guided by the V-beam radar installation at near-by Jamestown. During October, additional storms were surveyed utilizing Tinker Field Air Base, Oklahoma City, Oklahoma, as the center of operation. During the season 21 thunderstorms were surveyed and 65 traverses were made over the centers of the storms. Results of the season's operations may be summarized as follows:

The electrical conductivity of the atmosphere increases with altitude up to the limit surveyed (48,000 feet) in a manner consistent with that found on the balloon flight of *Explorer II*. This variation may be expressed closely by an equation of the general form $\lambda_h = \lambda_0 + Ah^2$, where λ_h and λ_0 are the positive conductivities (at height h and at ground level, respectively). A is a constant with a mean value of 2.0×10^{-8} , if h is expressed in feet, but varied on 6 flights from 1.6×10^{-8} to 2.4×10^{-8} . The mean value of λ_0 is 0.7×10^{-4} esu, but it varied on 6 flights from 0.4×10^{-4} to 1.4×10^{-4} esu.

The conductivity over the thunderheads surveyed appeared to be similar to that found at the same altitude away from the strong fields of the thunderhead.

The vertical current passing through the storms surveyed varied from a small fraction of an ampere to more than 6 amperes.

The arithmetical mean of the total current taken over the 21 storms is 1 ampere. The arithmetical mean, regarding each of the 65 traverses as independent, also amounts to 1 ampere.

The direction of the current on all 65 traverses was such as to return negative charge to ground. This is opposite to the sign of the air-earth current over fair-weather areas.

The sign and magnitude of the current, if the storms surveyed on this project can

be regarded as typical, are such as just to maintain, by thunderstorm activity, the negative charge of the earth, which is demonstrated on a world-wide basis by an air-earth current of the same sign over all fair-weather areas. These studies provide the experimental basis for a satisfactory explanation of this long-standing puzzle of the maintenance of the earth's negative electrical charge.

Atmospheric Conductivity in Peru

The atmospheric-electric data recorded at Huancayo during the winter of 1947 have been thoroughly studied with the object of determining the causes of the large diurnal variation in atmospheric conductivity which has been recorded at Huancayo for some years. There is a variation by a factor of about 3 between the maximum and minimum values.

The negative conductivity shows a greater variation than the positive. This has been found to be due to a diurnal variation in negative small ion mobility, which varies in such a way as to augment the effect of the variation in negative small ion content. The mobility of the positive small ions remains constant, so that the diurnal variation of positive conductivity is due entirely to variation of positive small ion content, which, in fact, is greater than the variation of negative small ion content. Average values of mobility from all data are: $k_+ = 2.3$ cm²/volt/sec, $k_- = 2.9$ cm²/volt/sec. Reduced to sea-level pressure, these values are: $k_+ = 1.6$ cm²/volt/sec, $k_- = 2.0$ cm²/volt/sec.

Values of positive small ion content were found to fit the formula of ion balance: $q = \alpha n_1 \cdot n_2 + \mu_{12} \cdot n_1 \cdot m_2 + \eta_{12} \cdot n_1 \cdot N_2 + \eta_{10} \cdot n_1 \cdot N_0$, where q is ionization, n_1 positive small ion content, n_2 negative small ion content, m_2 negative intermediate ion content, N_2 negative large ion content, N_0

neutral condensation nuclei content, and α , μ_{12} , η_{12} , η_{10} are the appropriate combination coefficients. These data furnish the following values of the combination coefficients: $\alpha = 0.9 \times 10^{-6}$ cc/sec, $\eta_{12} = 4.6 \times 10^{-6}$, $\eta_{10} = 0.4 \times 10^{-6}$, and $\mu_{12} = 3.3 \times 10^{-6}$ in the period 5^h to 10^h and 10.5×10^{-6} in the period 14^h to 18^h, with intermediate values from 10^h to 14^h.

These figures show that the variation in small ion content can be attributed to the following causes in the proportion shown: variation in ionization 25 per cent, variation in intermediate ion content 12 per cent, variation in large ion content 63 per cent.

There is strong evidence that the change in μ_{12} is due to the presence of more than one type of intermediate ion and an increase in the proportion of the less mobile types from morning to afternoon. On the other hand, values of η_{12} derived from day- and night-time data are surprisingly consistent.

These results are calculated without correcting the measured values of q for the fact that sources of alpha rays are excluded from the inside of the chamber. This correction will increase them by a factor of about 5/3.

If a correction is made for the exclusion of alpha-ray sources, both the total ionization figures and the percentage due to alpha rays are found to be unusually high. The table on the following page summarizes the results.

UPPER ATMOSPHERIC RESEARCH

Work directed toward exploratory geophysics of the upper atmosphere has progressed substantially along the lines indicated in the report for 1947-1948. Major effort has been devoted to the design, assembly, and testing of electronic devices and components required for the conduct

	DAY		NIGHT	
	Ion pairs/ cc/sec	Per cent	Ion pairs/ cc/sec	Per cent
Alpha rays in air. . .	30.0	76	38.4	80
Gamma rays in air	1.4	4	1.8	4
Gamma rays from ground and in- herent ionization of chamber	2.8	7	2.8	6
Cosmic rays	5.0	13	5.0	10
Total.	39.2	100	48.0	100

of special experiments utilizing electromagnetic waves for exploration of the upper atmosphere. An experiment to determine the precise time of certain sunrise characteristics of the ionosphere has revealed new facts concerning the structure of the upper atmosphere. Improved laboratory facilities at the Derwood Experimental Laboratory have materially raised the efficiency of operation.

Panoramic Recording of the Ionosphere

Development of a prototype high-speed ionospheric recorder has continued with the following objectives: (1) ability to explore the ionosphere at intervals of a few seconds in order to record rapidly changing phenomena; (2) maximum flexibility of operation over the entire frequency range, 1–20 Mc, or any portion thereof; and (3) completely self-contained standards of time and frequency assuring dependable performance under a wide range of operating conditions.

Although technical details of instrumental improvements are included in other reports, it is of interest to note that a technique has been developed which makes it possible to approach the ultimate theoretical limit of resolution. When an ionospheric recorder is swept over a wide band

of frequencies in a few seconds, the difference in frequency between a given transmitted pulse (and the corresponding receiver tuning) and the ionospheric echo from an earlier pulse becomes a limiting factor. This "detuning effect" is dependent on rate of change of frequency between pulses, velocity of propagation of radio waves, and maximum height range of the instrument. The new development automatically compensates for the frequency change between pulses, with the result that scanning speeds can be increased and receiver performance improved through better ratios of signal to noise.

Construction of two ionospheric recorders for operation in arctic and equatorial regions has continued. Many of the components have been completed and others are well advanced. All important instrumental design problems have been solved, although some mechanical problems such as antenna structures for field installations are still being studied.

The sunrise experiment of May 5 to June 10, 1949 has revealed new facts concerning properties of the outer atmosphere. It has also demonstrated the adaptability of a high-speed recorder for the precise timing of events within the ionosphere. Recordings were made daily from 04^h 30^m to 05^h 45^m at intervals of 5 or 10 seconds. Analyses were performed to determine the precise time at which a characteristic "sunrise effect" was observable in the F region. Although the time of sunrise in the F region was at least 1½ hours before ground sunrise, no increase of F-region ionization or other characteristic "sunrise effect" was observed until approximately 20 minutes after ground sunrise. This corresponds to a grazing angle of 5° or a solar zenith angle of 85°, representing a limiting angle at which the F region must be inclined to the sun's rays before a sunrise effect is observed from the ground. Nearer to the

time of ground sunrise it is inferred that the ionizing energy of the sun's rays is completely absorbed in the already illuminated atmosphere.

Several additional occurrences of ionospheric "clouds" and rapid fluctuations in ionization were recorded during the above-mentioned observing period. The dates of occurrences corresponded to magnetically quiet periods, in contrast with the magnetically disturbed interval of the original report on this phenomenon. The cause of such ionospheric "clouds" is still open to conjecture, although some evidence appears to be accumulating in favor of horizontal wind motions rather than clouds of extraterrestrial origin.

Duplex-Channel Differential Recorder

The basic principles and fundamental objective of the duplex-channel differential recorder were described in the report for 1947-1948. It will be recalled that the basic idea underlying the new development involves simultaneous transmission of radio waves on two channels separated by a small increment of wave frequency. The instrument is adjusted to record a selected characteristic of the ionosphere. The device "locks on and follows" the time variations of this characteristic and records the data on a pen-and-ink chart for immediate and greatly simplified analysis.

The computer section of this instrument, which incorporates complicated electronic counting and timing devices, has been finished and tested. Detailed circuit diagrams and descriptions of operating sequence have been prepared. Other basic circuits for all except the radio frequency components have been tested in preliminary assemblies. Operation of this instrument as an integral unit is anticipated early in the ensuing report period.

Experimental Cosmic-Ray Research

Large ionization chamber. The large ionization chamber installed at the Derwood Experimental Laboratory has been operating for several months, providing sufficient statistical data to determine the level of statistical fluctuations with the upper half of the chamber unshielded. As anticipated, large variations were found; these are doubtless due to changes in the local radioactive content of the air. This confirms the expected necessity of completely shielding the instrument with lead to eliminate these variations, which are large enough to obscure the solar-flare effects that the meter was designed to detect. Lead shielding is now being installed on the upper half of the meter.

Neutron chamber for cosmic rays. It is planned to use two available Compton-Bennett ionization chambers to record variations in cosmic-ray neutron flux. One chamber will contain $B^{10}F_3$ with enriched boron 10, and the other $B^{11}F_3$ with enriched boron 11, both isotopes now being available from Oak Ridge. Neutrons, slowed down by hydrogenous shields, are captured in boron 10 with emission of alpha particles, the ionization of which is recorded. No neutron capture occurs in the boron 11; thus by recording the difference in ionization between the two chambers, all ionization except that due to neutrons is canceled out. It is expected that such a neutron intensity recorder, especially at a high-altitude station, may be much more sensitive to changes in cosmic-ray intensity associated with solar flares, magnetic storms, and other causes than are the Compton-Bennett meters, which mainly measure meson intensity.

World-wide network of Compton-Bennett meters. Continuous recording of cosmic-ray ionization in Compton-Bennett meters was effected at Godhavn (Green-

land), Cheltenham (Maryland, U. S. A.), Huancayo (Peru), and Christchurch (New Zealand).

A new control box for Compton-Bennett meter no. C-4 was completed. This meter, badly damaged in transit from Teoloyucan (Mexico), has been thoroughly overhauled, assembled, and filled with argon. Comparisons between meter C-4 and meter C-1 are now in progress at Cheltenham to insure that quantitative changes in intensity at Climax and at Cheltenham due to solar

flares may be reliably compared. Since there is little difference in latitude and about 11,000 feet difference in elevation, quantitative comparison of solar-flare effects at these two stations should provide some indication of the nature of cosmic-radiation changes associated with solar flares. Dr. Walter O. Roberts, Director of the High Altitude Observatory at Climax, Colorado, has kindly co-operated in providing space for meter C-4, and will endeavor to insure its continuous operation.

THEORETICAL AND STATISTICAL STUDIES

COSMIC-RAY RESEARCH

Mechanism for the Solar-Flare Effect on Cosmic Rays

Work was continued in collaboration with Dr. M. S. Vallarta on a mechanism to explain the marked increase in cosmic-ray intensity observed during a few solar flares. As mentioned in previous annual reports, the rate of change of the magnetic moments of sunspot pairs appears sufficient to provide protons with enough energy, by a process analogous to that of the betatron, to reach the earth at latitudes where the cosmic-ray increases during the solar flares were observed. Except in unusual circumstances, protons of this energy, about 7 Bev, would escape from the sun only at regions very near the poles, and not at regions nearer the sun's equator, where flares are observed. The magnetic moment, however, of a pair or group of sunspots seems to provide the necessary and unusual circumstance permitting the particles to escape. To be certain whether the magnetic moment of sunspot pairs makes it possible for protons of the energy involved to escape through the sun's general magnetic field requires the integration of the equations of motion of a charged particle in the combined magnetic field of the sun

and of the sunspot. The equations of motion were set up in Cartesian co-ordinates and several points along a trajectory were obtained by numerical integration using two different numerical schedules, one of which was kindly furnished by Dr. J. von Neumann to insure that the numerical schedule could be handled by the Eniac electronic computer at Aberdeen, Maryland.

From results of a few numerical integrations, obtained with ordinary mechanical computing machines, it was found that only a very short interval of integration (arc length along a trajectory) could be used if the errors of integration were to be kept sufficiently small. This was due to the fact that the trajectory of the particle is roughly helical, with radius small compared with the solar radius. Consequently, to compute a trajectory long enough to determine whether the particle escapes from the sun would have taken, even for the Eniac, a prohibitively large number of integrations. Since the motion of the particle is approximately helical, the equations of motion have been transformed into helical co-ordinates. Parameters in the equations allow for the expected changes in the pitch and radius of the helix along the trajectory. In this system of co-ordinates it is expected

that, for a given accuracy, a much greater interval of integrations can be used than was the case for the integrations carried out in a Cartesian system. Work on the numerical schedule for the integration is now being started. By the fall of 1949 the results of the preliminary integrations should determine whether the problem can be solved in a reasonable time on the Eniac. The possibility of investigating the tunnel problem on the magnetized model of Malmfors and Alfvén was examined also. The model, because of its limited magnetic moment and the lower limit of useful electron energy for the beam, could only simulate the actual problem for a sun with magnetic moment much less than 10^{34} gauss cm^3 , the figure indicated by the cosmic-ray latitude variation, or for protons of energy much greater than the 7 Bev indicated by the latitudes at which solar-flare effects on cosmic-ray intensity were observed.

Search for Systematic Variations in Cosmic-Ray Intensity

It has been pointed out by M. S. Vallarta and O. Godart that periodic variations of small amplitude are to be expected if the sun has a total steady magnetic moment of 10^{34} gauss cm^3 , as required to explain the knee of the latitude variation in cosmic-ray intensity. They have also indicated that a periodic 27-day variation in intensity would occur if the solar magnetic moment were sufficiently inclined to the axis of rotation, since in that case the solar cut-off energy would vary with the period of the sun's rotation. As a consequence of the inclination of the sun's axis of rotation to the ecliptic, a 6-month periodic variation was predicted whether or not the rotational and magnetic axes coincide. Data from several Compton-Bennett meters, obtained over a period of ten years or more,

were subjected to analyses to determine whether any of the predicted variations could be regarded as statistically significant. The 27-day variation was found to be quasi-periodic like the 27-day recurrence phenomenon in terrestrial magnetic activity. The amplitude of the periodic 27-day wave was too small to be regarded as statistically significant. The 6-month variation had maxima in reasonable agreement with the predicted times of maxima, although the amplitude was too small to be regarded as statistically significant. The results obtained therefore do not confirm, although they clearly do not deny, the existence of the periodic variations predicted on the basis of a permanent solar magnetic field.

Cosmic-ray data covering a period of about ten years were analyzed for a sidereal diurnal variation. Some indication of a sidereal wave was obtained, but its statistical significance has yet to be tested. The influence of the earth's magnetic field, however, on the interpretation of an apparent sidereal variation has only been worked out (Vallarta and others) for cosmic rays arriving vertically at the geomagnetic equator. This work shows that coincidence telescopes would be much better suited for interpretation than are Compton nondirectional meters.

GEOMAGNETIC STUDIES

An examination was made of the worldwide pattern of abrupt magnetic-field changes during the simultaneous initial phases, or "sudden commencements," of intense magnetic storms. According to the Chapman-Ferraro theory of magnetic storms, the electric currents causing the sudden commencement flow well beyond the atmosphere. These currents, which produce a field at the earth like that of an external dipole, and the effects of the

electromagnetic shielding of the ionosphere have been estimated by Price. Examination of the two sudden commencements which occurred during the Polar Year 1932-1933 has yielded results indicating agreement with theory, and the fields of two more sudden commencements are now being examined in an effort to draw more certain conclusions from the study. This work was begun with the co-operation of Sr. Mateo Casaverde, of the Instituto Geofísico de Huancayo, while he was a guest of the Department.

The westward motion of the magnetic dipole best fitting the earth's main field was investigated. This dipole is displaced from the center of the earth about 300 km in the direction of the East Indies. Since 1840, its motion, as shown from spherical harmonic analyses, has been westward at the rapid rate of about 0.25° of longitude per year. From the indications of declination charts, this motion seems to have been continuing at about this rate since A.D. 1600. This westward shift and the accompanying shifts of the irregularities in the earth's field have an important bearing on theories of the earth's main field; an internal structure deep in the earth is retarded, in its rotation about the axis, more than the crust is retarded. This gives us clues to dynamical properties of the core. This work is being continued with special reference to the results of varve measurements, which provide magnetic data over a longer time scale.

The weekly staff discussion on geophysical problems mentioned in last year's report were continued with active participation of other colleagues in the Washington area. During the fall of 1948, Professor V. C. A. Ferraro, of the University of the South West, Exeter, England, gave a series of lectures, followed by discussion, on theories of magnetic storms and aurora and of the ionosphere. The focus of attention

was the formulation of new problems susceptible of theoretical or experimental approach with particular reference to the electrical state of the upper atmosphere.

Hourly Frequency of "Sudden Commencements"

A statistical examination of the hourly frequency of geomagnetic "sudden commencements" was initiated in order to check the rather striking results obtained by Newton from his analysis of the Greenwich magnetograms. All available traces from several observatories in various geomagnetic latitudes and longitudes were examined, and it was found that only stations of latitude above about 30° produced curves which showed a systematic diurnal variation. When only sudden commencements which were followed by the larger magnetic storms were considered, this diurnal variation was more pronounced. A tabulation was also made of the ratio of those sudden commencements having a small preliminary impulse (Newton's sudden commencements) to all sudden commencements, and the results from seven observatories appeared to show that this ratio varies with geomagnetic longitude. Further data are being sought from the magnetograms of other observatories in strategic positions in order to reach a definite conclusion on this point.

Portable Magnetic Observatory

Active experimental study is being given to the development of an automatic, long-run, portable magnetograph capable of being set up in an isolated place and left to record the three geomagnetic elements without attention for several months. The basis of this proposed new instrument is the portable magnetograph developed during the war, with such modifications as appear necessary for the desired prototype

of a group of general-purpose recording instruments which can provide the information ordinarily provided only by a permanent magnetic observatory and staff.

LABORATORY PHYSICS

NUCLEAR PHYSICS

The major emphasis during the past year has been on the problem of proton-proton scattering in the relatively low-energy region of 200 to 500 kilovolts, using the one-million-volt electrostatic generator. This is the region which will be most sensitive to the exact shape of the potential well which is assumed in each analysis of proton-proton scattering; it will respond particularly to a possible long-range "tail" on the steep-walled potential well. This is a difficult region of energy for measuring proton scattering because of the difficulty in observing protons of low energy and in measuring accurately the number of protons in the incident beam during operation, with hydrogen gas necessarily present in the scattering chamber. A considerable measure of progress has been made during the year on these problems. Proportional counters have been built and operated which will reliably count protons having as low as 90,000 electron volts energy. It has been found that the proton beam current can be monitored by allowing the beam, after passing through the scattering volume, to bombard a lithium target; observing the number of alpha particles emitted in the disintegration of lithium of mass 7, the number of such particles will be proportional to the proton beam current. Preliminary scattering data have been taken in the region 300,000 volts. Efforts are now being directed toward reducing possible systematic errors in the data.

The high-resistance column[†] used for measuring voltages on the one-million-volt generator has been overhauled during the

year. New Western Electric precision resistors were installed, and the assembled unit was carefully calibrated against the sharp gamma-ray resonances from boron, lithium, and fluorine bombarded by protons.

During the early part of the year, in cooperation with Dr. D. R. Inglis, of Johns Hopkins University, and Dr. E. M. Hafner, of Brookhaven National Laboratory, experiments were completed on the study of the proton groups emitted in the disintegration of carbon of mass 12, bombarded by deuterons. The yield and angular distribution curves of the protons were obtained for deuteron energies from 1 to 3.5 million electron volts. This work illustrated the complexity of the nuclear energy-level system in this region of the atomic table. As many as 21 levels of the intermediate nucleus (nitrogen 14) were observed.

BIOPHYSICS

The biophysics group continues to approach biological problems from the viewpoint of physics. The group is more convinced than ever of the benefits to be derived from cross-fertilization between the various disciplines. In addition to the three staff members of the group who are physicists by training, there are present among visiting investigators and fellows a cell physiologist, two biochemists, and an organic chemist.

To gain a more solid background for the biophysics program, a considerable effort has been made and is continuing in group study. In one series of seminars the book entitled *Dynamic aspects of biochemistry*, by Baldwin, was thoroughly covered. In

a second series, *Radiation effects*, by Lea, was presented. In addition, a number of outside visitors and lecturers presented other facets. Among the guests were Margaret Murray, B. A. d'Houssay, David Pressman, Alan A. Boyden, A. Szent Györgyi, William Libby, L. H. Grey, J. W. Boag, Britton Chance, and Robert Briggs.

The biophysics program is continuing to evolve. One of the principal preoccupations is the formulation of questions and modes of approach to central problems in biology in terms appropriate to men trained in physical sciences. The nature of some of the basic puzzles encountered by physical scientists in living matter has been examined. This educative process has given rise to focusing of attention on a number of points generally related to the problem of "early life." The role of metals which have the capacity for change of valence as active centers of enzymes and coenzymes, and the importance of trace elements as clues to biological processes, both currently and in the very distant past, are examples of the type of problem which has attracted interest and roused extended discussion. These studies of biological processes have brought the biophysics group into close contact with the men concerned with geochemistry, and the resulting discussions have outlined a new field of research relating to the early history of the earth.

While examining and formulating larger problems, the group has continued to make a considerable number of specific research contributions. The work during the report year has largely been concerned with metabolic and physiological studies using radioactive isotopes, and with studies of biological effects of radiation. Among the results of projects under way or reaching completion are the following:

Studies employing proteins labeled with radioactive iron (in collaboration with

Louis B. Flexner, of the Institution's Department of Embryology, and Gilbert J. Vosburgh, of the Department of Obstetrics, Johns Hopkins University and Hospital) have thrown new light on the turnover rate from the plasma of the guinea pig to the extravascular fluid. The observed rate was slow (0.3 to 1 per cent per minute) in comparison with that previously found for electrolytes. The substance employed was ferric beta₁-globulinate, produced by biological synthesis from inorganic radioactive iron. Another investigation was a determination of the turnover rate of chloride ion from plasma to extravascular fluid space. The value found was a rate of 60 per cent per minute, which, perhaps significantly, is the same as that observed earlier for sodium. The two results when taken together clearly cast doubt on the "pore theory" of capillary permeability.

A further study was a comparison of the permeability of *Escherichia coli* to sodium and potassium ions. It was found that the cellular membrane is completely permeable to both sodium and potassium and that the sodium ions within the water space in the cell are in equilibrium with those in the medium. This water space constitutes 75 per cent of the volume of the cells. There is no fixation of sodium in resting, growing, or highly metabolizing cells. Potassium ions can also diffuse freely across the membrane, but the picture of pure diffusion is complicated by metabolic processes which fix the potassium in a nondiffusible form.

The importance of potassium in biological processes has long been recognized. Potassium, sulphur, and phosphorus are the most important chemical constituents of the ash of most cells, each one contributing roughly 30 per cent of the total. Potassium is also a major constituent of fertilizers, since it is known to be necessary to plant nutrition. Whereas, however, the

roles of phosphorus and sulphur are well recognized, the actual biochemical function of potassium is not at all clear.

It is known, for example, that potassium, unlike sodium (which is chemically similar), is concentrated by cells, and that the potassium once taken up by the cell is not readily removed. Consequently, it has been inferred that the potassium is bound in some way to some component of the cell. Compounds or complexes with proteins, carbohydrates, and fats have been postulated, but none of these has ever been isolated or identified.

Experiments at the Department using radioactive potassium produced by the cyclotron have given some new light on this problem. It was found that the incorporation of one molecule of glucose by cells of *E. coli* caused the binding of two atoms of potassium. As the glucose was broken down further, the potassium was released. Other experiments indicated that the potassium was bound in the cell as potassium salts of the hexose phosphates which are the immediate products of glucose metabolism. This hypothesis was further supported by the observation that during the period when two potassium atoms were bound, one phosphate group was transferred to the glucose molecule. Thus, potassium apparently participates in the major process by which the cell obtains energy from its food supply.

Furthermore, it was possible to obtain new information concerning the metabolism of glucose by observing the uptake and loss of potassium. Some of the results could be interpreted to show that a large fraction of the glucose is consumed by direct oxidation rather than by the more familiar and better-understood phosphorylative mechanism. In a system as delicate and complex as a cell, any new method of observation is highly valuable, particularly when it does not interfere in any

way with the normal metabolism of the cell. Further work along these lines is in progress using potassium and rubidium, together with phosphorus and sulphur.

Another project under way is a study of the rate of uptake of radioactive fluoride in normal enamel. The work (in collaboration with Dr. F. A. Arnold, Jr., and Dr. R. C. Lichens, of the Dental Research Institute, National Institutes of Health) includes a study of the chemistry of fixation of topically applied fluorine. The biophysics group is especially in a position to be helpful in this project. The tracer fluorine employed cannot be produced in the nuclear reactor; a cyclotron is required.

Further study of P^{32} uptake in *Arbacia* eggs has provided additional knowledge regarding the chemical form of the phosphorus immediately after it enters the cell. Fertilized eggs were immersed in sea water containing very small amounts of phosphorus in the form of inorganic phosphate. On chemical analysis after a few minutes' exposure, the P^{32} in the eggs was found in at least three fractions: inorganic phosphorus, adenosine triphosphate, and hexose monophosphate.

Studies on the influence of the thyroid on calcium metabolism were continued by Dr. H. H. Darby, Research Associate of the Institution, who worked at the Department throughout the year and participated in many of the activities and discussions in biophysics. The influence of vitamin D on the damage done to the thyroid by thiouracil was checked. The work reported a year ago was completely confirmed.

An attempt was made to determine the part of the thyroid on which vitamin D does its work, and whether the parathyroid is involved. Many researchers believe that the parathyroid is involved in calcium metabolism. In none of the animals to which the thiouracil was fed was there any

histological change in the parathyroid, but an immense change in the thyroid was found. When the vitamin D was fed, no histological change was observable in the parathyroid, whereas large changes were seen in the thyroid itself. The central areas of the thyroid seem to respond better to the vitamin D than do the peripheral areas, and there appears to be a difference between the anterior and the posterior part of the thyroid. Co-operative research with Dr. Pauline Beery Mack, of Pennsylvania State College, on X-ray density measurements of the epiphysis has led to interest in this type of work at the National Institutes of Health, and, to a lesser degree, at the Naval Medical Research Institute.

The essential mineral elements for the proper functioning of a biological system have in the past been thought to be the more abundant substances, such as calcium, sodium, potassium, iron. At the same time, the literature has many statements that a particular element has been found necessary in extremely small amounts for some particular animal. Animal husbandry and research have traced certain disease conditions to the shortage of such trace elements and have cured these conditions by the addition of extremely small amounts of the element to the animal's food. Many years ago in New Zealand, Australia, and Scotland a disease of sheep was shown definitely to occur when there was a shortage of cobalt. It was cured by the addition of cobalt sulphate to the pastures on which these sheep were fed. No reason was given for the necessity for this cobalt.

Recently in the continuation of the search for more B vitamins (the water-soluble vitamins), vitamin B₁₂ was discovered and in the chemical breakdown was shown to contain cobalt. It was separately found that cobalt was required by the bacteria in the sheep's rumen, not

primarily by the sheep. Another significant finding at this time was that this active biological material B₁₂, the pernicious anemia factor which had previously been thought to be found only in liver, was also found in the excreta of cows and fowls. A combination of the work in Scotland and Australia on cobalt and the B₁₂ work in the United States and England now was possible, especially since radioactive cobalt was available from the Department's cyclotron. With this in mind, sheep were fed radioactive cobalt, and a collection was made of the excreta. This was then analyzed both for the cobalt and for B₁₂, using microbiological tests. The cobalt was found in the excreta in more than one chemically bound form, but one of the forms was that of B₁₂.

The B₁₂ molecule was then traced to its synthesis in the bacteria which occur in the rumen or first stomach of the sheep. It is interesting here to note that the cow is also a ruminant and that the fowl has a double type of stomach in the gizzard and the crop. Any two-compartmented stomach like this will give a much longer period for food to be acted upon by bacteria than will a single stomach. In these animals, therefore, the bacteria are playing a significant role in the production of necessary nutrients for the host animal. Other bacteria, including *E. coli*, were shown to take up cobalt and synthesize it into B₁₂.

The fundamental characteristic that first attracted investigators to this substance was that it seemed to be necessary for the building of proteins. In fact, the first name given to it by the English workers was "animal protein factor." Since there is necessarily an immense amount of protein building of all types in the developing embryo, it was of interest to follow a B₁₂ molecule from the digestive tract of a hen into the egg. Radioactive cobalt was given hens by mouth and was found to be de-

posited in the yolk, in the albumen, and to a very much less extent in the shell and its inner lining. In this manner it was possible to show that such a trace element as cobalt, which was fed at the level of a few micrograms per day, appears in the egg and plays a significant role at a level of a hundredth of a microgram per gram. The whole field of biological significance of trace elements is of challenging interest. Especially important are those elements that are bivalent and can help in forming intermediary compounds, even if these are highly transitory and have so far escaped discovery in the chemistry of the test tube, which differs markedly from the chemistry of the body.

A series of studies of biological effects of radiation has been carried out by Dr. W. R. Duryee, of the National Cancer Institute, working at this laboratory. Through observations on transparent living amphibian ovarian eggs, he has been able to develop new and objective criteria of radiation damage. These involve chromosomal fragmentation, nuclear damage, and changes in nature of colloidal suspensions within the nuclei. Using these criteria, he has been able to show that by subjecting amphibia to temperatures of 6° C, appearance of radiation damage can be postponed for as much as two weeks. Using a micro-injection technique, he could render normal cells abnormal by injection of radiated cytoplasm, whereas injection of nonirradiated cytoplasm did not produce nuclear damage.

The lethal effect of ultraviolet radiation on bacteria is well known, but the mechanism is not at all clear. During the past year it was found that after irradiation the

bacteria (*E. coli*) were highly sensitive to many factors in the environment which had no effect on normal bacteria. Under certain conditions the bacteria would recover from the effects of the radiation and remain viable. A study of these conditions indicated that the enzyme systems had been thrown out of balance. It is probable that this unbalance was caused by cellular poisons produced by photochemical reactions within the cell.

In December 1948 it became clear that a number of young nuclear physicists had suffered radiation injuries leading to lens cataracts. In view of the widespread interest in this tragic occurrence, the Department felt it desirable to foster a survey and assessment of the situation. It seemed particularly worth while to conduct the investigation in such a way as to avoid duplicating efforts and thus to prevent unnecessary trouble for the men involved.

Acting in collaboration with Professor P. Gerald Kruger, of the University of Illinois, and with the encouragement and support of the Division of Medical Sciences of the National Research Council, survey questionnaires were sent to the various high-voltage laboratories of the country. A three-day session was held in Washington, in January 1949, which was attended by all individuals known to be afflicted. This was followed by ophthalmological examination at Johns Hopkins. The Department subsequently prepared a report of the findings of the meeting for the National Research Council, which was distributed to all high-voltage laboratories. It is hoped that this effort may aid in the prevention of future injuries.

OPERATIONS AND STAFF

CO-OPERATIVE WORK OF THE DEPARTMENT

Co-operation has been continued with individuals and organizations in this country and abroad in accordance with the Institution's policy.

Research work on the earth's crust and cosmic rays has continued under Navy contracts N70nr-290 and N70nr-459, respectively, with advantage to the Government as well as to the Institution. These contracts provide for co-operative activity and the loan of equipment, but conform to the policy of no direct cash subsidy to the Institution for added or existing staff or facilities. A new task order under the first contract provides for one member of the staff to engage in co-operative research with the Navy for a limited period on atmospheric-electric problems. Some members of the staff have continued to assist various offices of the Government as consultants; one has been on full-time leave of absence for the entire year, and another since April 1, 1949.

Although the observatories at Huancayo, Peru, and Watheroo, Western Australia, have been owned and operated by the Peruvian and Australian governments since July 1, 1947, the Department retains a lively interest in their activities and has been privileged to co-operate in matters of program policy and operational detail. Messrs. Casaverde and Fernandez of the Huancayo staff were in residence in Washington as Fellows of the Institution for six months each, to receive training at our laboratory and others in the Washington area.

Sounding balloons were supplied to Professor G. Bernardini in Italy for research work there.

The Department has continued to have the advantage of collaboration with Dr. Louis B. Flexner, of the Department of

Embryology, in the biophysics program, and with representatives of the National Institutes of Health, National Bureau of Standards, Applied Physics Laboratory of the Johns Hopkins University, Brookhaven National Laboratory, Wilmer Institute, Department of Obstetrics of the Johns Hopkins University, and Catholic, Georgetown, George Washington, Howard, and Tulane universities.

The biophysics group has continued its responsibility for the operation of the cyclotron and the production of radioactive isotopes, which have been distributed without charge to some forty different groups in this country and abroad.

Dr. M. S. Vallarta, of Mexico, has continued to collaborate with the Department in the investigation of sudden increases in cosmic radiation associated with solar flares. Dr. John R. von Neumann, of the Institute for Advanced Study, has also assisted in this work. In addition, four observatories, previously mentioned, have continued to operate the Compton-Bennett cosmic-ray meters.

Joint experiments in the seismic program of the Department and the Geophysical Laboratory were carried out in close collaboration with Columbia University and New Mexico School of Mines, as well as with Navy and Army groups. Again grateful acknowledgment is made to the Navy (Office of Naval Research and Bureau of Ordnance) for under-water explosions scheduled for the convenience of our observers, and to the Tennessee Valley Authority for the unusual opportunity offered by the three large blasts at the South Holston Dam site.

We are greatly indebted to the U. S. Geological Survey for valuable assistance in selection of localities and sites for the rock magnetism studies.

PUBLICATIONS

In addition to the scientific papers appearing in current literature, two volumes of the *Researches of the Department* have been published, containing results of cosmic-ray and earth-current observations; they are listed under "Major publications" in the bibliography.

It is intended to publish, as Publications of the Carnegie Institution of Washington, the magnetic results from the Watheroo and Huancayo observatories (which were transferred to the respective local government agencies on July 1, 1947) for the years 1945 to 1947, the results through 1945 having already been published. The preparation of these two final volumes is now under way.

ADMINISTRATION AND OPERATION

A special experimental license W3XAU was obtained for observations on meteors.

Five panel trucks are now on loan from the Navy for use in the seismic investigations.

A modest quantity of surplus electrical material was obtained through the District of Columbia Educational Agency for Surplus Property.

The *Journal of Geophysical Research*, edited by the Director, with the help of Mr. Walter E. Scott, received support from the Institution. This journal is the continuation of the *Journal of Terrestrial Magnetism and Atmospheric Electricity*, edited for many years by Dr. John A. Fleming.

The Department continues to have the advantage of visits from guest investigators for varying periods. These are included in the appended list, which also shows the regular members of the staff, most of whom were employed for the entire report year.

SEMINARS

The recent work of Urey, Brown, and Libby has clearly demonstrated the rich discoveries that can be made by applying modern physical techniques to geophysics. Several staff members of the Department visualized the possibility that a survey of geological problems on the basis of familiarity with new techniques of physics and chemistry would bring to light new and significant problems and opportunities. It was particularly obvious that a great gap in man's knowledge is the period between the origin of the earth and the Cambrian. Accordingly, with the collaboration of the Geological Survey and the Geophysical Laboratory, a seminar was organized which had for its principal theme "Milestones in the Pre-Cambrian." The subjects discussed, during March 4 to May 13, 1949, were: Harrison Brown, Isotopic analysis of the universe; R. B. Roberts, Origin of the earth; G. Gamow, Origin of the universe; W. D. Urry, Radioactivity and the age of the earth; W. D. Urry, The radioactivity of potassium; H. E. Tatel, Radioactivity and the earth's cooling; M. A. Tuve, The mass spectrometer; H. C. Urey, Separation of isotopes by chemical processes; P. H. Abelson, Separation of isotopes by physicochemical methods; H. C. Urey, Temperature measurements on fossil shells by use of isotopic analysis; D. B. Cowie, Dating in the earth's immediate past by use of C^{14} ; E. Ingerson, The Pre-Cambrian; E. Ingerson, Isotopic separation by geologic processes; R. B. Roberts, Creation of the earth's atmosphere; W. W. Rubey, Origin of the ocean; H. H. Darby, The origin of life (as formulated by Oparin); M. A. Tuve, An alternative mode for the origin of life; L. H. Adams, The nature of the earth and its origin; N. L. Bowen, Formation of the earth's crust; W. W. Rubey, Mountain building; W. H.

Bradley, The problem of the ocean basins.

Some of the interesting potential research problems arising out of the talks and discussions were: (1) The possibility of detecting evidence of life earlier than the fossils by studies of trace-element patterns in sedimentary rocks or Precambrian graphite. (2) The possibility of determining a geological level corresponding to the time of appearance of living matter on earth. Since the oxygen of the atmosphere is derived from biological activity, a drastic change in the earth's atmosphere must have occurred at that time. Simultaneously, isotopic abundances must have shifted slightly. (3) The possibility of determining whether the granites are of sedimentary or of magma origin by observations of the trace-element patterns in such rocks. (4) Fractionation of hydrogen isotopes as a measure of hydrogen escape from the atmosphere.

During the period September 24 to De-

cember 20, 1948, Dr. V. C. A. Ferraro, of England, gave a series of lectures on "Geomagnetic storms and the upper atmosphere."

LECTURES GIVEN BY VISITORS

September 3, 1948, "The cause of the earth's magnetism," by E. C. Bullard.

September 24, 1948, "Gravity and the isostatic structure of the earth," by W. Heiskanen.

October 20, 1948, "A mechanism to explain increases in cosmic-ray intensity during some solar flares," by M. S. Vallarta.

December 21, 1948, "Cosmic-ray investigations," by Marcel Schein.

February 23, 1949, "Cosmic-ray investigations in Italy," by G. Bernardini.

March 4, 1949, "Isotopic constitution of meteors," by Harrison Brown.

May 19, 1949, "Work with C¹⁴," by William F. Libby.

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MAJOR PUBLICATIONS

- Cosmic-ray results from Huancayo Observatory, Peru, June, 1936-December, 1946; including summaries from observatories at Cheltenham, Christchurch, and Godhavn through 1946. By I. LANGE and S. E. FORBUSH. *Researches of the Department of Terrestrial Magnetism*, vol. XIV. Carnegie Inst. Wash. Pub. 175. v + 182 pp., 12 figs., 207 tables (1948).
- Earth-current results at Tucson Magnetic Observatory, 1932-1942. By W. J. ROONEY. *Researches of the Department of Terrestrial Magnetism*, vol. IX. Carnegie Inst. Wash. Pub. 175. v + 309 pp., frontispiece, 10 figs., 318 tables (1949).

STAFF AND ORGANIZATION

SCIENTIFIC STAFF

Staff Members:

- Geophysics:* L. V. Berkner, S. E. Forbush, O. H. Gish (retired September 30, 1948), E. A. Johnson (on leave of absence for governmental research), W. J. Rooney, H. E. Tatel, O. W. Torreson, M. A. Tuve, E. H. Vestine, G. R. Wait, H. W. Wells.
- Laboratory and Biophysics:* F. H. Adelson, D. B. Cowie, N. P. Heydenburg, R. B. Roberts, M. A. Tuve.
- Guests, Associates, Fellows, and Visiting Investigators:* P. Bhattacharya, India; E. O. Bowles, American University; M. Casaverde, Geophysical Institute of Huancayo, Huancayo, Peru; S. K. Chakrabarty, India; H. H. Darby, Miss E. Dollman, Brookhaven National Laboratory; W. R. Duryee, National Institutes of Health; G. Fernandez, Geophysical Institute of Huancayo, Huancayo, Peru; V. C. A. Ferraro, University of the South West, Exeter, England; P. S. Gill, Tata Institute of Fundamental Research, Bombay, India; J. W. Graham, Johns Hopkins University; E. J. Habib, Catholic University; Miss

E. Hill, National Cancer Institute; R. Hossfeld, Catholic University; D. R. Inglis, Johns Hopkins University; F. Irreverre, Experimental Biology and Medicine Institute, U. S. Public Health Service; W. C. Knox, National Institutes of Health; T. Murphy, University College, Dublin, Eire; J. N. Nanda, India; A. T. Ness, U. S. Public Health Service; R. Nieset, Tulane University; W. D. Parkinson; Mrs. I. Z. Roberts, National Cancer Institute; F. L. Talbott, Catholic University; M. S. Vallarta, Instituto de Física, Universidad de México, D. F., and Comisión Impulsora y Coordinadora de la Investigación Científica, México, D. F.; P. Wang, National Bureau of Standards; W. D. Whitehead, Jr., University of Virginia; F. W. Wood, Australia.

OPERATING STAFF

- Administrative:* M. B. Smith, W. F. Steiner.
- Office and Clerical:* Mrs. J. H. Campbell, J. J. Capello, W. N. Dove, H. D. Harradon, W. C. Hendrix, Miss H. E. Russell, A. D. Singer.

Instrument Shop: B. J. Haase, L. A. Horton,
J. G. Lorz.

*Research Assistants, Laboratory Assistants, and
Technicians:* Miss E. Aldous, S. J. Buynitzky,
J. B. Doak, P. A. Johnson, C. J. Ksanda, C. A.
Little, Jr., P. F. Michelsen, P. L. Moats, A. E.
Moels,* W. C. Parkinson, R. W. Reuschlein,
Miss M. Sands, W. E. Scott.

* Resigned.

Computers: Miss E. Balsam, Miss I. Lange.

Maintenance: C. Balsam, C. W. Burger,* C.
Domton, S. W. Malvin (retired December 31,
1948), E. Quade, M. A. Quade.

Part-Time and Temporary Employees: There
were 18 part-time and temporary employees
engaged during the year, usually for short
periods, to assist in the office and laboratory
work.

SPECIAL PROJECTS: TERRESTRIAL SCIENCES

FRANK T. GUCKER, JR., Indiana University, Bloomington, Indiana. *Studies of specific heats of aqueous solutions up to high temperatures.* (For previous report see Year Book No. 46.)

This is a continuation of the study of specific heats of salt solutions up to 85° C., carried out in collaboration with Dr. Frank W. Lamb, during which there was found a maximum in the apparent molal heat capacities of three typical uni-univalent electrolytes at about 60° C., and a decrease at higher temperatures. This is exactly opposite to the increase above 65° predicted by F. Zwicky, on the basis of the theory of electrostriction and of Bridgman's P-V-T data for water, and shows that either the theory or the data require revision. An extension of the experiments up to the critical point (218 atmospheres and 375° C. for pure water) seemed desirable in order to supply data in a region where none are available, and where a theoretical interpretation may be simpler, since most of the anomalous properties of water become less pronounced at higher temperatures. The experiments require a new type of calorimeter, suitable for work at high temperatures and pressures. This year, with the collaboration of Mr. Jean M. Christens, a suitable bomb calorimetric apparatus has been designed and nearly completed, and the extensive auxiliary equipment necessary for these measurements has been assembled.

A differential system was chosen, with water as the reference substance in one of the twin calorimeters, and solution in the other. The heat capacity of the solution is measured relative to that of water, which has been studied carefully up to the critical point by Osborne, Stimson, and Ginnings at the National Bureau of Standards. Each calorimeter is provided with a single small

tube connected to the bottom, through which it can be evacuated and water or solution can be introduced. In order to avoid the formation of any vapor during an experiment, with consequent absorption of a large amount of heat, a constant hydrostatic pressure of about 220 atmospheres is maintained, measured by means of an accurate dead-weight gauge. A strong, thin calorimeter is obtained by constructing the shell of Inconel, in two nearly hemispherical halves, held together by means of a threaded ring at the center. A platinum lining prevents corrosion by the salt solutions under the severe experimental conditions. An electrical immersion heater with metal fins distributes the heat inside the calorimeter without the use of a stirrer, and a thick plating of silver on the outside of each calorimeter helps to equalize the surface temperature and to reduce radiation. The electrical heating is regulated to raise the temperature of the two calorimeters at practically the same rate, and the difference in temperature is measured by means of a 16-junction thermel connected to points distributed over the surface of each calorimeter.

The calorimeters are held within a steel case which can be evacuated to about 10⁻⁴ mm. of mercury to prevent thermal conduction. Within the case is a heavy copper adiabatic jacket surrounding the calorimeters, provided with electrical heaters to maintain the desired uniform temperature, measured by multiple thermels between it and the calorimeters and also by a platinum resistance thermometer. A series of thin, highly polished aluminum shields re-

duces the radiation between the calorimeters and the copper jacket, and a second series of these shields reduces the radiation to the outer case, which is near room temperature. The large evacuated space reduces the hazard from failure of the calorimeters, and a second steel case surrounds the whole apparatus as a further precaution.

The apparatus, with its bombs of known volume, dead-weight pressure gauge, and platinum resistance thermometer, may be used to measure the compressibility, ther-

mal expansibility, and vapor pressure of solutions, as well as their specific heats. The auxiliary apparatus also would be useful in the measurement of the dielectric constant of water over a wide range of pressure and temperature. It is hoped that such measurements can be carried out, since the pressure and temperature coefficients of the dielectric constant are needed to calculate the limiting slopes of the apparent molal heat capacities, volumes, compressibilities, and expansibilities of solutions.

DIVISION OF PLANT BIOLOGY

Stanford, California

C. STACY FRENCH, *Director*

The attack on photosynthesis has been concentrated primarily upon those parts of the initial steps in the photosynthetic process which involve the photochemical splitting of water molecules, rather than upon the ensuing reactions by which carbon dioxide is reduced. Thus the general program of one group of investigators has centered about the absorption of light by plant pigments, the possible transfer of the absorbed energy from one pigment to another, and the correlation of these events with the ultimate chemical changes produced in living plants.

A broad survey, extending over a period of years, of the specific chloroplast pigments which are found in the various groups of photosynthetic plants has just been completed. From this work it has become evident that the pigment complexes characteristic of the main plant families were developed early in the course of evolution, and have remained constant in spite of the great changes in the external form of plants.

Experiments with seedlings initially grown in the dark have shown that during their subsequent exposure to light the formation of chlorophyll is much more rapid than had previously been realized. Even with moderately weak light an appreciable fraction of the protochlorophyll is converted to chlorophyll *a* in a few seconds. From measurements of the effectiveness of different wave lengths of light on this transformation in corn and bean seedlings, it was found that only the light which is absorbed by protochlorophyll, and not that absorbed by any other pigments present, can lead to chlorophyll formation.

It is now considered likely that chlorophyll *b*, which develops later than chlorophyll *a*, does not originate from chlorophyll *a*. A study of the correlation of pigment formation with the development of other parts of the photosynthetic apparatus has been started.

The first detectable chemical effect resulting from absorption of light by the pigments of the photosynthetic apparatus of plants is the splitting of water, which results in oxygen evolution and the reduction of some 'unidentified intermediate. For the experimental investigation of the reaction, it is possible to replace the unknown natural intermediate by certain common chemicals, such as a reducible dye. By ejecting a suspension of chloroplasts at high pressure through a fine needle valve, one obtains colloidal suspensions of material the particle size of which is much smaller than that of the so-called grana. This material is in a form suitable for chemical studies of the water-splitting step of photosynthesis. The activity of such a preparation is about one-third that of the original chloroplast suspension. Nearly all the original activity can be restored, however, by treatments which cause a partial reaggregation of the individual colloidal particles. Thus there are at hand some means for correlating morphology and function at a size level between the molecular and the microscopically visible ranges.

The suggestion that controlled cultures of algae may become a valuable source of foodstuffs has received rather surprising and widespread attention. This interest in a process deviating from traditional meth-

ods of food production is no doubt due to the compelling nature of the present problems of world food supply and the concern which has been aroused by popular discussion of the social factors involved in these problems.

Some of the more important constituents of the products formed by *Chlorella* have been established: of the carbohydrates, starch and cane sugar have been isolated; of the lipids, the fatty acids have been identified; and it has been found that all the ten essential amino acids are present. From an industrial viewpoint, however, a great deal remains to be learned regarding the practicability of producing *Chlorella* on a large scale and the use that may be made of its products. These problems are essentially of an engineering nature. For their further investigation an arrangement has been effected between the Carnegie Institution of Washington and the Research Corporation. The latter has, in turn, given financial support to the Stanford Research Institute to make an intensive study of the process and the products on a pre-pilot plant scale, with the co-operation of the Carnegie Institution of Washington.

The records of the transplant and crossing experiments on *Potentilla glandulosa* discussed in last year's report have been further analyzed. The genetic linkage between various morphological characters and certain physiological variations upon which the natural distribution depends has been thus established. Species which are widely distributed in various environments are able to fit these diverse conditions because such species consist of many physiologically and genetically distinct races. Each of these races fits a different set of environmental conditions. A better understanding of evolution should be attained by the study of the genic-physiological relationships of suitable plant groups.

The effective prosecution of such experiments is dependent upon the utilization of species which show a wide range of form and adaptation to different environments and which grow rapidly. The suitability of the genus *Mimulus* for such work is being tested by transplanting, by crossing, and by morphological observation.

The success of the Edinburgh plantings of a number of the strains of range-grass hybrids developed by the Division has led to an increase in the number of strains tested there by the Scottish Society for Research in Plant Breeding and to the undertaking of many similar plantings to supplement those made by the Soil Conservation Service of the U. S. Department of Agriculture. Thus co-operative experiments on forty-six strains have been arranged with a number of widely scattered laboratories. This has been done to test the climatic adaptability of *Poa* hybrids over a wide range of climatic conditions such as are found in the state of Washington, southern California, North Carolina, Scotland, Wales, Holland, Denmark, Norway, and Sweden. No universally outstanding strain has been produced, but several of the selected strains show excellent performance in a number of environments. Under different environments different strains are observed to give superior growth. Fortunately, many of these improved strains breed true from seed, thus being easy to distribute. A detailed cytological investigation is being conducted on the mechanism of seed and of pollen formation and on the way in which these processes are influenced by the environment. Some of these grass hybrids of particular interest have been selected and are being grown in preparation for a quantitative experiment on their growth response in controlled laboratory environments.

The taxonomic treatment of western

North American Poas rounds out the comprehensive gathering of knowledge of the distribution, cytology, genetics, physiology, and evolution of this economically important genus of plants.

In close co-operation with the staff, a number of visiting scientists have been

carrying out related investigations with different species of plants. By drawing upon their experiences and new materials, the Division's program, which traces the complex evolutionary patterns by which plants evolve, has been both broadened and strengthened.

PERSONNEL

BIOCHEMICAL INVESTIGATIONS

Staff: C. Stacy French, *Director*, Harold W. Milner, James H. C. Smith, Herman A. Spoehr, Harold H. Strain

Fellows: Violet M. Koski, Fergus D. H. Macdowall

Research Assistants: Marie L. G. Koenig, Nancy S. Lawrence, George H. Towner

Mechanic: Frank Schuster

Systematics and Genetics, Royal Agricultural College, Uppsala, Sweden, National Swedish Research Fellow

Stanford graduate students associated with the Division: Robert K. Vickery, Jr., George H. Ward

Research Assistants: Robert W. Ayres, Helen K. Sharsmith, Mary H. Wagner
Gardener: Wesley B. Justice

EXPERIMENTAL TAXONOMY

Staff: Jens C. Clausen, Paul Grun, William M. Hickey, David D. Keck

Fellow: Herbert G. Baker, Lecturer in Botany, Department of Botany, University of Leeds, England

Guest Investigators: Pierre Dansereau, Directeur du Service de Biogéographie, University of Montreal, Guggenheim Fellow; Hedda Nordenskiöld, Institute of Plant

RESEARCH ASSOCIATES

Ralph W. Chaney, Professor of Paleontology, University of California, Berkeley, California

SECRETARY

Wilbur A. Pestell

CUSTODIANS

William F. Larson, Jr., James W. Groshong

BIOCHEMICAL INVESTIGATIONS

CHLOROPLAST PIGMENTS

HAROLD H. STRAIN

Pigments and evolution. For millions of years, life on the earth has required a continuous supply of organic matter. Throughout the long geologic ages, most of this organic material has been produced by the photosynthetic activity of green plants. In all plants, this remarkable photochemical action hinges upon the utilization of sunlight by the pigments contained within the microscopic chloroplasts of the plant cells. Through this reaction, the chloroplast pigments harness the atomic

fires of the sun for the production of oxygen and organic matter on the earth. In this way, the chloroplast pigments form an indispensable part of the complex organizational machinery required for the maintenance of virtually all living things.

In the search for clues to the evolution of the photosynthetic apparatus and to the evolutionary development of plants and of animals, much time has been devoted to determination of the pigments of present-day plants. Plants belonging to most of the major botanical families have now been obtained from various geographical habi-

tats, and their chloroplast pigments have been isolated and compared by the sensitive chromatographic adsorption method. These plants were collected from such diverse environments as Hawaii, the high Sierra Nevada of California, the western North American desert, the coastal regions of California, mountain lakes and streams, and the sea near California, Hawaii, and North Carolina. Some of the plants were native to arctic regions, others to tropic and to temperate regions. Some of the cultivated plants were native to such remote places as Japan, China, Malaya, India, the Mediterranean region, Africa, Madagascar, the Pacific islands, and North and South America. Most of the marine plants were obtained from the intertidal zone, but some of them were dredged up from depths of 50 to 100 feet.

The pigments of all these plants showed no significant variation with habitat. There was, however, a unique correlation between the occurrence of certain pigments and the taxonomic families to which the plants belong. In conformity with earlier results, all the higher plants yielded the same principal pigments, usually in about the same proportions. In a few organisms, the proportions of the several xanthophylls varied significantly. Whereas lutein was usually the principal xanthophyll, violaxanthin occasionally predominated, and in one plant (*Fremontia californica*) zeaxanthin was at least equal in amount to lutein.

Among a large number of algae, the presence of certain chlorophyll and carotenoid pigments was also found to be characteristic of the principal taxonomic groups. As there is some question concerning the classification of certain algae, knowledge of the pigments provides another guide for establishment of their relationship. For example, the fresh-water *Vaucheria* contains pigments also found in

the Heterokontae, the yellow-green algae, of which some five unicellular species grown in pure cultures have now been examined. The similar fresh-water *Dichotomosiphon* and the marine *Derbesia* contain pigments characteristic of the siphonalean green algae of the order Chlorophyceae. Such observations on the functional pigments of the plant cells provide significant links between the fields of chemistry, physiology, taxonomy, and phylogeny.

There has been wide acceptance of the view that the so-called complementary pigments of algae have developed in response to the spectral quality of the incident light. Algae growing in deep water and receiving a preponderance of blue-green light are presumed to have developed pigments which complement the weak absorption of the chlorophyll for green light. But in the algae dredged up from deep water, the pigments were found to be characteristic of the plant group; they were not determined by the conditions under which the plants grew. If there has been any effect of light on the development of the pigment systems, the change must have occurred before evolution of the plants known today.

All these diverse facts indicate that the pigment systems characteristic of the major botanical families were established early in the evolution of the plant world. Although plants have varied enormously in form and in adaptation to different environments, the pigment system shows no corresponding variation. Even though the pigment system is remarkably unstable in killed plant material, in living organisms it is one of the most constant physiological systems ever developed.

As man and animals depend upon organic substances of particular molecular structure that stem from photosynthesis,

the pigments can be regarded as the mold in which the molecular building bricks of the organic world are formed. At this molecular level, pigments may possibly establish the pattern of asymmetry that permeates the entire organic world, and thus they may set a limit to the variability of plants as well as of animals.

One may well ask the question, Why is the system of chloroplast pigments subject to so little variation? A partial answer lies in the fact that variations of the pigment system induced by injury or by mutation usually block the photosynthetic process. Consequently, plants thus changed will be eliminated rapidly from the native populations, because they will have lost their capacity for self-nourishment and independent existence. If this intimate connection between the pigment system and the photosynthetic process is the true explanation for the constancy of the pigments, then this dependence, too, must have been established millions of years ago, before the establishment of the plant groups that are known today. But there may be other causes for the constancy of the pigment system, and these are being sought in further studies of the pigments and their reactions.

Enzymatic oxidation of the chlorophylls. Through the use of adsorption methods, a rapid enzymatic oxidation of the chlorophylls to other green pigment has been discovered. This oxidation reaction varies with the conditions under which the leaves are killed, and with the plant material. Of the plants tested, it was most rapid in the young leaves of barley and of potatoes. It occurs rapidly when leaves of these plants are permitted to stand with organic solvents in the presence of oxygen. It does not occur in the absence of oxygen or in leaves that have been exposed to heat.

The products of the enzymatic oxidation of the chlorophylls are spectrally similar to the unaltered pigments, but are somewhat more adsorbed than the chlorophylls in columns of powdered sugar, so that, with experience, they are easily isolated. Each chlorophyll yields a single oxidation product, and in this respect the enzymatic oxidation differs from the spontaneous oxidation of the chlorophylls in methanol. This oxidation in methanol (known as allomerization) yields several oxidation products, one of which is identical with the product of the enzymatic oxidation. The enzymatic oxidation takes place in the presence of small amounts of water; the allomerization in methanol, by contrast, is inhibited by small amounts of water.

Chlorophylls themselves yield interconvertible isomers when the pigments are heated. The oxidation products do not yield the analogous isomers. Apparently the oxidation of the chlorophylls alters that portion of the pigment molecule involved in the isomerization reaction.

Improvements of the chromatographic adsorption method. In spite of its remarkable sensitivity and its wide applicability to chemical separations, the chromatographic adsorption method has not found wide application in industry. One of the limitations to separations by this method on an industrial scale is the discontinuous nature of the procedure. Now, however, a modification of the column has been devised so that certain adsorbed substances can be forced to migrate horizontally as well as downward. As a result, the flow of liquid through the column can be made continuous while the components of the mixture are collected in the respective portions of the percolate. Experiments to test applications of this continuous procedure are under way.

THE PHOTOCHEMICAL ACTIVITY OF DISINTEGRATED CHLOROPLASTS

H. W. MILNER, N. S. LAWRENCE,
M. L. G. KOENIG, AND C. S. FRENCH

The studies on the photochemical splitting of water by chloroplast material have been continued with much the same ultimate objectives as were described in the report last year. Progress in this investigation has been made in several lines, one of the most interesting of which has been the finding of certain large increases in the activity of the material upon reaggregation of very finely divided colloidal solutions of chloroplast material.

The dispersion of chloroplasts into extremely small particles is now accomplished much more simply and effectively with a new device. In last year's report the use of supersonic vibration for this purpose was described. It now appears that more effective results may be obtained by extruding the suspension of chloroplasts in water containing 15 per cent methanol through a fine needle valve under high pressure. The equipment for this consists simply of a round steel bar 3 inches in diameter with a 1-inch round hole 4 inches long in its center. Into this is fitted a steel plunger with a rubber and a leather washer. The bottom of the hole in the steel bar is tapped to receive a steel needle valve. In use, the whole assembly is placed in a hydraulic press. When the pressure on the liquid rises to 20,000 pounds per square inch, the needle valve is opened slightly and, with the pressure held at this level, is adjusted to maintain a flow of about 5 cc. of liquid per minute. Under these conditions it is possible to obtain about three-fourths of the chloroplast material in a state of fine dispersion which will withstand centrifuging for one hour at 12,000 times the force of gravity without

sedimenting. By this treatment the activity of the chloroplast material is reduced to about one-third of its initial value. These preparations appreciably exceed those obtained by any other method so far investigated in fineness of particle size and in total yield, and they are prepared with greater ease.

The stabilization of such preparations, which has long been the greatest technical difficulty, has been considerably improved through the discovery of the stabilizing effect of 15 per cent methanol in the aqueous suspension medium. By the use of this concentration of methanol it is possible to retain half of the original activity of these preparations for a week by storing the material at -5° C. Thus a single preparation can be used for experiments extending over several days. Equimolar concentrations of ethanol are equally satisfactory for stabilization at very low temperatures, but are inferior to methanol at higher temperatures. The stabilizing influence of methanol was found during an attempt to use it as a means of fractionally precipitating the proteins in this mixture. Even in concentrations as high as 95 per cent and in the absence of salts, methanol or ethanol does not cause the formation of a precipitate except after standing for several hours at room temperature.

In solutions with 15 per cent methanol, however, the addition of small amounts of salts causes precipitation of chloroplast material. In water solutions without methanol a higher salt concentration is required to produce a precipitate. The appearance of this precipitate at salt concentrations of 0.1 M or lower is accompanied by a great increase in activity under illumination, sometimes by as much as two or three times, above that of a similar suspension without the salt. This activity is never

greater, however, than that of the intact chloroplasts. It appears that the aggregation caused by the salt takes place in such a way that several active centers catalyzing the reaction are brought closer together.

This activation differs from the chloride effect described in the work of other laboratories in that the new effect depends upon a reaggregation of the particles. Furthermore, other salts such as sulfates give even greater effects than do chlorides. This activation connected with precipitate formation is produced by a treatment of the material with salt at relatively high concentrations in aqueous methanol, and is not found when traces of salts are added to the reaction mixture, as in the case of the chloride effect.

This activation phenomenon, which has caused considerable difficulty in the assay of fractions obtained by salt precipitation, has, however, proved to be of considerable interest for its own sake. This effect may be related to the arrangement of the lipids present in the material. The participation of the lipids became evident when it was found that extracting the dispersion of chloroplast material with petroleum ether abolished or greatly reduced the salt activation effect. This extraction removes about 2 or 3 per cent of the total lipid which is present. After the petroleum ether extraction, the capacity of the dispersions for activation by salt may be re-established by treating the material with a small amount of ethyl ether, then evacuating to remove the ethyl ether completely.

One difficulty in separating the active components from the inactive substances by fractional precipitation has been inability to obtain complete redispersion of the precipitates. This also prevents comparable activity measurements on the precipitated and dispersed material. The use

of detergents in combination with adsorption techniques offers some hope of overcoming these difficulties.

THE OXIDATION-REDUCTION PROPERTIES OF CHLOROPLASTS

F. D. H. MACDOWALL

The photosynthetic reaction is now considered to be composed of two main steps: the splitting of water, which results in the evolution of oxygen and the formation of a reducing substance; and the reduction of carbon dioxide by the substance formed in the first step. Illuminated chloroplasts, even though removed from living cells, cause the reduction of a number of substances but not the reduction of carbon dioxide. A greater negative electric potential is required for the reduction of carbon dioxide than for that of the substances which are reduced by isolated chloroplasts. It was therefore of interest to find out what reducing power, as expressed in terms of electric potential, may be reached in suspensions of illuminated chloroplasts.

Measurements were made of the potentials of bright platinum electrodes immersed in suspensions of chloroplast material containing various added reducible dyes. Illuminated suspensions always showed a lower potential than nonilluminated ones. The lowest observed potential, referred to the standard hydrogen electrode, was -0.25 volt. It was found that the potential of such suspensions was lower in freshly prepared material than in that which had stood for a short time. It thus appears that chloroplasts in intact leaves may be able to produce an appreciably greater negative potential than that attained by isolated chloroplasts, perhaps even a potential effective for the reduction of carbon dioxide.

DEVELOPMENT OF THE MECHANISM FOR THE
EVOLUTION OF OXYGEN

JAMES H. C. SMITH

When leaves grown in the dark are illuminated, they develop the ability to liberate oxygen from carbon dioxide. We do not now know at which stage during the course of illumination the ability to liberate oxygen originates, nor at which stages other parts of the photosynthetic processes have their beginnings.

One of the first observable changes connected with the development of the photosynthetic apparatus during the illumination of dark-grown seedlings is the conversion of protochlorophyll to chlorophyll *a*. According to current concepts of the structures of these two compounds, this conversion is a hydrogenation of protochlorophyll. It seemed possible that the hydrogenation of protochlorophyll might be involved in the splitting of water, which at the same time would result in the evolution of oxygen. Therefore, the first experiment performed to correlate the events that lead to the development of the complete mechanism for photosynthesis was a determination of whether oxygen is evolved during the transformation of protochlorophyll to chlorophyll *a*.

Two very sensitive methods were used to test for the evolution of oxygen during this photochemical transformation, namely, the emission of light by luminescent bacteria, and the quenching of the phosphorescence of tryptaflavine adsorbed on silica gel. Under the conditions of the tests, the evolution of oxygen was not detected by either method. From these experiments there is no evidence that the transformation of protochlorophyll to chlorophyll *a* produces oxygen. Furthermore, etiolated leaves seem to be incapable of evolving even traces of oxygen immediately upon being illuminated.

Green leaves and etiolated leaves have also been compared with respect to their ability to liberate oxygen after being placed in a vacuum in the dark and then illuminated. Under these conditions, in the absence of carbon dioxide, green leaves quickly evolve a limited quantity of oxygen but etiolated leaves evolve no oxygen. These facts suggest that during greening the leaves develop a potential reservoir for photosynthesis from which they can liberate oxygen by photochemical action.

The oxygen liberated by illumination of the evacuated leaves was estimated by measuring the quenching of the phosphorescence of tryptaflavine adsorbed on silica gel. A phosphorometer of simple design was constructed for this purpose. This instrument was capable of detecting oxygen pressures of the order of 10^{-5} mm. of mercury. Since the quenching is proportional to the logarithm of the oxygen pressure, the method is more sensitive in the lower ranges of oxygen pressure.

THE NATURE OF THE TRANSFORMATION OF
PROTOCHLOROPHYLL TO CHLOROPHYLL

V. M. KOSKI AND J. H. C. SMITH

It has been known for some time that most higher plants do not form chlorophyll in the dark and that the rate of chlorophyll formation which takes place in the light is affected by temperature. Therefore, the biosynthesis of chlorophyll must involve both thermochemical and photochemical reactions. A more detailed analysis of the effect of light and temperature on the greening of leaves has demonstrated that the formation of protochlorophyll is a thermochemical reaction and the transformation of protochlorophyll to chlorophyll is strictly a photochemical reaction.

Protochlorophyll accumulates in plants grown in the dark at room temperature,

but it is not formed either in the light or in the dark at 0° C. These observations make it clear that protochlorophyll is formed by a thermochemical process.

Since light is involved in the transformation of protochlorophyll to chlorophyll *a*, the question arises as to whether this transformation is a mixture of thermochemical and photochemical reactions or whether it is a strictly photochemical reaction. This was tested by measuring the rate of the reaction at different temperatures and different light intensities.

The rate of transformation of protochlorophyll in dark-grown corn leaves was measured at two temperatures, 5 and 18° C., and at three light intensities, 30, 120, and 240 foot-candles. The rates at the two temperatures were identical for each of the three light intensities and were roughly proportional to the light intensity. Because the rate of the transformation is independent of the temperature and proportional to the light intensity, it may be concluded that the rate determining step is photochemical.

The rate of transformation is very rapid. Light energy of 240 foot-candles from a 40-watt 4500 White Westinghouse fluorescent lamp converts 56 per cent of the protochlorophyll in 10 seconds.

The transformation reaction was also measured with monochromatic light as the source of illumination. Light of wave lengths 640 and 650 mμ, each having a band width of 5 mμ, was used. An analysis of the rates showed the transformation to obey strictly the mathematical expression for second-order reactions.

As a result of these experiments it may be concluded that in etiolated corn leaves the transformation of protochlorophyll to chlorophyll *a* is limited by photochemical action, and that the rate of transformation is determined by the amount of light absorbed by the protochlorophyll.

In the previous Year Book it was reported that in continuous light, transformation of the protochlorophyll present in etiolated seedlings produces chlorophyll *a*. As greening progresses, chlorophyll *b* appears. Thereafter, chlorophylls *a* and *b* increase in constant proportion to each other. Similar results have now been obtained from experiments with intermittent light. These relations make it highly improbable that chlorophyll *b* is derived from chlorophyll *a*.

THE ACTION SPECTRUM FOR THE FORMATION OF CHLOROPHYLL

J. H. C. SMITH, V. M. KOSKI, AND C. S. FRENCH

The possible transfer of energy between pigments and the chemical utilization of light energy absorbed by plant pigments can be investigated in a system similar in many respects to photosynthesis. This system is the photochemical mechanism by which protochlorophyll is changed into chlorophyll by the action of light. This reaction is, in a limited way, analogous to the photochemical steps of photosynthesis in that it takes place in the leaf and the active pigment is very closely related to chlorophyll. It is simpler than photosynthesis in that protochlorophyll, the pigment concerned in the absorption of light, is also the substance which is transformed by the action of the light, and in that the product of the reaction, chlorophyll, is a known chemical substance. The process of greening of dark-grown leaves involves a system of better-known components and fewer chemical steps than does photosynthesis, and yet it is a system closely associated with photosynthesis and one in which the utilization of light energy can be more easily investigated. Under certain conditions it is possible in this system to measure a photochemical transformation which is not complicated by a number of thermochemical steps.

The specific question which this analogous reaction can help to answer is one relating to the possible participation of several different pigments in causing a single type of photochemical change to take place. It has been well established that photosynthesis may be powered by light energy absorbed by a number of different pigments. In all these cases chlorophyll *a* is always present, and it is considered likely that the energy absorbed by the other pigments is in some way transferred to chlorophyll *a*, which then initiates the first steps of photosynthesis.

In the greening of etiolated plants there is also the possibility that nonchlorophyllous pigments such as carotenoids may participate by the absorption of light and the transfer of energy to protochlorophyll. A series of experiments carried out a few years ago in another laboratory can be interpreted in this way. Whether or not light absorbed by chlorophyll can be used to cause further chlorophyll formation has long been of interest. The older methods are not adequate to settle this question.

The development in this laboratory of procedures for the extraction and analysis of chlorophyll and protochlorophyll, as well as the construction of a device for the production of high enough intensities of monochromatic light throughout the visible spectrum, has made possible a greatly improved reinvestigation of these long-discussed questions.

By means of these new techniques the effectiveness of various wave lengths of light in producing given effects in biological material can be accurately measured. If the absorption spectra of the pigments contained in the biological material are known, it is then possible to compare the action spectrum with the absorption spectra of the pigments and thus to see clearly which pigments are photochemically active.

Precise measurements have now been made of the action spectrum for the transformation of protochlorophyll to chlorophyll in normal and albino corn and in normal bean seedlings. The results make it evident that the carotenoid pigments not only are ineffective, but reduce the action of the blue light by absorbing it. Thus they act as a light filter at short wave lengths. The results with normal corn and bean leaves are in distinct contrast with the older work on oats, in which it was found that the carotenoids, even though present in abundance, did not cause internal screening. In albino corn, which contains very small quantities of carotenoids, blue light was found to be the most effective part of the spectrum.

Another experiment was performed in which about one-half the protochlorophyll present in the leaf was converted into chlorophyll, and the leaf was then illuminated with light having a wave length of 6800 Å, which is strongly absorbed by chlorophyll, but very weakly absorbed by protochlorophyll. This illumination at 6800 Å gave no significant increase in chlorophyll content. It is therefore evident that red light absorbed by chlorophyll is not involved in the transformation of protochlorophyll.

It may be said in conclusion that only light which is absorbed by protochlorophyll is active in the transformation of this pigment to chlorophyll. The action spectrum obtained for this transformation in albino corn seedlings, which contain little other pigment than protochlorophyll, gives therefore a measure of the absorption spectrum of protochlorophyll in living etiolated leaves, a result which cannot be obtained directly because of the low concentration of this pigment in such leaves.

SPECTROSCOPIC EQUIPMENT

C. S. FRENCH, J. H. C. SMITH, AND
GEORGE H. TOWNER

The recording spectrophotometer mentioned in last year's report has been considerably improved, but is not yet ready for routine use. The major change has been the incorporation of a cam which is run by the wave-length drive mechanism to take care of most of the necessary corrections. The remaining small corrections are now handled by the curve follower, an arrangement which provides for considerably greater accuracy. A means has been devised for the automatic plotting of this secondary correction curve. Comparison of the spectral absorption curve for a pure sample of chlorophyll *a* as recorded by this machine with that measured manually by another instrument indicates that the maximum error in measuring the per cent transmission is now within 3 per cent. The stability and reproducibility are somewhat better than this figure. The apparatus is now being rebuilt for greater precision, increased stability, and freedom from scattered light. From the experimental work to date, it appears that its eventual performance should be well within 1 per cent for the measurement of absorption spectra, and within a few per cent for the spectroradiometry of very weak light beams, such as the fluorescent light from leaves or algae.

A large-aperture grating monochromator has been built for the measurement of the effectiveness of different parts of the spectrum in the formation of chlorophyll in dark-grown leaves. The results of these experiments are discussed in a separate section of this report. This monochromator is based on a diffraction grating kindly loaned by Mr. Harold Babcock, of the Mount Wilson Observatory. This 4 by 4 inch grating, with 15,240 lines per inch.

is used with two large camera lenses designed for aerial photography. The lenses have an aperture ratio of $f/2.5$ and 12 inches focal length. The angle between the two optical axes is 30° , the grating being placed at the intersection of the two axes and rotated about this point by a screw-drive mechanism. This screw drive is provided with a double thread and a positioning pin moved by a cylindrical correcting cam so that for each revolution of the drive wheel, 100 angstroms of the first-order spectrum is swept across the exit slit. The wave lengths of light in the spectra of both the first and second orders are thus strictly proportional to the amount of rotation of the drive wheel and can be read continuously by means of separate counters for the two orders. Readings of these counters are correct within 5 angstroms. The first-order dispersion is 50 angstroms per millimeter. The maximum transmission of the instrument in the first-order spectrum is in the red, and in the second order it is in the blue. The light source used in conjunction with this instrument is a high-pressure capillary mercury lamp. This combination produces adequate intensity in a 50-angstrom band width for studying the formation of chlorophyll in leaves at all points throughout the visible spectrum.

Another monochromator for use in the recording spectrophotometer has been made. This instrument has a similar collimator lens and a 4 by 4 inch transmission replica grating obtained through the courtesy of Professor R. W. Wood, of Johns Hopkins University. This grating, with 14,000 lines per inch, has a high transmission in the first-order blue part of the spectrum. After passing through the grating, the light is reflected from a movable plane mirror which controls the wave length coming out of the instrument.

From this plane mirror the light goes to a spherical mirror of 63 cm. focal length. The image of the spectrum on the exit slit is thus about twice the size of the entrance slit. The linear dispersion in the plane of the exit slit is therefore 27 angstroms per millimeter. The drive wheel of this instrument is also arranged so that one rotation corresponds to 100 angstroms. These two instruments may be coupled together with selsyn motors, thus acting as a double monochromator to sweep the spectrum at a constant rate. Either of them can also be used independently for photochemical purposes.

THE URONIDES OF LEAVES

H. A. SPOEHR

Higher plants are composed primarily of carbohydrates. Cellulose, probably the most abundant organic substance occurring in nature, is the chief component of the structural and supporting parts of higher plants. Starch, one of the most common plant constituents, serves the plant as an important storage food material. Both cellulose and starch are formed by the linking together of a large number of sugar units of one type, namely D-glucose. Also of very wide distribution in all plants are the uronides. This group of carbohydrates is more complex than cellulose or starch in that its members are composed of more than one type of sugar unit, combined with either glucuronic or galacturonic acid. This greater complexity in composition of the uronides greatly increases the difficulty of gaining an understanding of the structure and properties of this class of compounds. Further difficulties arise from the colloidal character of the uronides and their occurrence in the plant in association with other carbohydrates, which makes clean separations extraordinarily difficult.

The phytochemical relations of the uron-

ides and their physiological function in the plant are still largely unknown. Yet their very complexity of structure and of chemical reactivity invites speculation concerning their role in the physiology and chemistry of the plant. It has been generally assumed that the uronides are primarily cementing elements in the structural fabric of plant tissue. But it is possible that in leaves they play a more dynamic role in the metabolism of the plant, as intermediates in the formation of other compounds, and even in the photosynthetic process. Before any such hypotheses can be tested with leaf material, considerably more exact information is required concerning the isolation, purification, and chemical composition of the leaf uronides.

Uronides have been isolated from several species of leaves, including sunflower, spinach, plane tree, and more particularly flax. It has been found advantageous to use leaves which are free of starch. The uronide content has been found to range from 8 to 15 per cent of the dry leaf material. The uronides are extracted with water, precipitated with ethanol, purified by repeated solution in water, and reprecipitated with alcohol. The product obtained in this manner is principally in the form of calcium salts with about 25 to 30 per cent uronic acid. On further purification, a water-soluble polyuronic acid is obtained, composed principally of galacturonic acid. The method of hydrolysis in which 90 per cent formic acid is employed, and which gave very satisfactory results with compounds composed of mannuronic acid and of hexoses and pentoses, is of no value with compounds containing galacturonic acid. This is apparently due to the fact that mannuronic acid readily forms a lactone which crystallizes well and the acid can be isolated in this form, whereas galacturonic acid does not form

a lactone. Although polygalacturonides can be hydrolyzed with 90 per cent formic acid, on concentration of the acid hydrol-

ysate the galacturonic acid rapidly undergoes condensation or polymerization to form insoluble compounds.

EXPERIMENTAL TAXONOMY

JENS CLAUSEN, DAVID D. KECK, WILLIAM M. HIFSEY, AND PAUL GRUN

Broadly interpreted, the experimental taxonomy program has as its threefold objective an understanding of the various kinds and degrees of kinships between plants, of the relations between plants and their environments, and of the evolutionary processes that have produced the diversity between plants and their fitness to the environment. Progress toward this objective becomes more and more a co-operative effort, not only within the staff itself but with outside individuals and institutions.

These investigations advance along an extended front, and during the year the groundwork has been laid for new approaches. Previously, the transplant studies had shown that widely distributed species are able to occupy their diverse environments because they are composed of many physiologically and genetically distinct races, each fitted to live in a different sector of the area occupied by the species as a whole. On the other hand, the experiments on the *Madiinae* and other plants had revealed the presence of various kinds of barriers to free interbreeding that have arisen during the process of 'speciation', giving rise to species and other units in various stages of differentiation. The processes through which plants become fitted to their environments remain to be explored. It is known that this fitness depends upon their physiological characteristics, which in turn are governed by genes, but the details of this interaction are unknown. Exploration of the genic-physiological relationships of appropriate plant groups may therefore hold an important key to our understanding of evolution.

Possibly no single organism can be found that fulfills all the requirements of a program in physiological and ecological genetics with these objectives, and probably several groups of plants are needed, each bringing to light features not so readily discovered in others. During the year progress has been made in the search for such groups of plants by testing the suitability of several different genera. These tests meanwhile serve to extend our knowledge of plant relationships, as all have interconnected objectives and aim toward the solution of related problems.

PERSONNEL AND GUEST INVESTIGATORS

During the year a larger group than ever before has participated in this program. Dr. Paul Grun, of Cornell University, joined the staff in March 1949. Dr. Herbert G. Baker, Lecturer in Botany at the University of Leeds, England, spent the year from October 1948 with the group on a Carnegie Institution Fellowship, investigating the evolutionary patterns in some plants having both an Old and a New World distribution.

Dr. Pierre Dansereau, Director of the Service de Biogéographie at the University of Montreal, was with the Division from March through August 1949 on a Guggenheim Fellowship. He was drawing upon the program in experimental taxonomy for material to include in a book on the taxonomy of the vascular plants, in which the aim is to correlate cytotaxonomy, ecology, and experimental methods with conventional taxonomy. He also familiarized

himself with the plant communities of the Pacific coast region, especially of the transect marked by the Division's stations, as a background for the correlation.

Dr. Hedda Nordenskiöld, of the Institute of Plant Systematics and Genetics of the Royal Agricultural College, Uppsala, Sweden, was a visitor in the spring of 1949 under a National Swedish Research Fellowship, collecting and studying western American forms of the wood rush, *Luzula*, to correlate with studies on that genus in western Europe. Two Stanford graduate students, Mr. Robert K. Vickery, Jr., and Mr. George H. Ward, have utilized the greenhouses and other facilities in researches intimately connected with the Division's program. These various visitors have brought many new points of view into the group.

POTENTILLA GLANDULOSA

This species of the rose family has many contrasting ecological races and is well adapted for genetic experiments, as was brought out in Year Book No. 47 (1947-1948). It is also a good subject for transplant experiments, since the segregating and cloned second-generation hybrids between races from lowland and high-altitude climates have proved excellent for the study of principles in ecological genetics. During the year the statistical analysis of the long-term selection experiments has been completed with the efficient aid of Dr. Helen K. Sharsmith, and a manuscript on these experiments is now in preparation. The physiological properties of the races and hybrids have not been investigated, however, as this species is difficult to clone and grows slowly, and hence is less well adapted for physiological studies than for the other approaches to ecological genetics.

HYBRIDIZATION IN *ACHILLEA*

The members of the *Achillea millefolium* complex occur almost throughout the northern hemisphere and have evolved an unparalleled series of contrasting climatic races. They clone easily and are excellent for physiological investigations (Year Book No. 45, 1945-1946, pp. 112-117), but they have only a few distinctive morphological characteristics that can be used as markers in a genetic investigation. The first seven F₁ hybrid combinations between contrasting races were made in 1948 and grown in 1949, as follows:

Achillea borealis, $n=27$ chromosomes:

San Joaquin Valley race, 36° N. × Kiska Island coastal race, 52° N.

San Joaquin Valley race × Kiska Island alpine race

San Joaquin Valley race × California coastal race

Achillea lanulosa, $n=18$ chromosomes:

Port Orford, Oregon, coastal race, 43° N. × Vera Cruz, Mexico, montane race, 7000 ft., 20° N.

Port Orford coastal race × California redwood region race

Port Orford coastal race × Great Basin race

Achillea millefolium × *borealis*:

Northern Iceland coastal race, 65° N. × San Joaquin Valley race, 36° N.

The most contrasting cross is between the giant San Joaquin Valley race of *A. borealis*, which is 150 cm. tall, winter-active, and from a continental subtropical climate in California, and the diminutive (8 cm. tall), winter-dormant, alpine, subarctic race of the same species from treeless Kiska Island in the Aleutians. It is expected that recombinations of the genes in the second generation of the hybrid of parents from such contrasting climates will produce offspring of great physiological variation.

EXPLORATORY STUDIES IN *MIMULUS*

A new plant being tested for its applicability to experimentation is *Mimulus guttatus*, the common monkey flower. It and its close relatives compose a highly variable group of plants that has evolved races all over western North America west of the Rocky Mountains from Alaska to Baja California, and from sea level up to 11,000 feet. Most of the races of *guttatus* are perennials, but some are annuals. Both perennial and annual forms may flower as soon as four months after sowing. They clone easily and cross easily, most forms are self-compatible, and a single pollination may result in hundreds of seeds. Cultivation is difficult, however, for this plant occurs naturally in moist soils or even in running water, although it can be grown to maturity without trouble under greenhouse conditions. Its adaptability to garden culture is now being tested.

Four F_1 hybrids between races of the *Mimulus guttatus* complex from very different climates along our station transect were grown this year, namely, coastal \times Sierran foothill; coastal \times alpine (*Mimulus Tilingii*); coastal \times subalpine Great Basin; Sierran foothill \times alpine (*M. Tilingii*). The crossings were easily made except those involving the alpine form, which has been known as a distinct species; and the hybrids appear to be fertile.

Since October 1948 Mr. Robert Vickery has carried on these investigations as a project for his doctor's degree through a co-operative arrangement between the Division and the Department of Biology of Stanford University. The experimental work is being done at our stations. Thirty-nine populations of 5 species of the *guttatus* complex have been grown in addition to 57 strains of 23 other miscellaneous species, and in all 7 of the 10 sections of the genus have been represented.

Seventeen races and forms of the *Mimulus guttatus* complex, mostly from our transect, have been crossed during the year in all possible directions. These strains came from the immediate coast, the coastal mountains, and a series of localities over the Sierra Nevada from the foothills on the west to 10,000 feet elevation near the crest and to the plateau of the Great Basin beyond, and included the closely related annuals *M. nasutus* and *M. laciniatus*. A Chilean form of *M. luteus* was also included.

In addition to these crossings, designed to explore thoroughly the interrelationships within a single section of the genus, these 5 species and 9 others, representing 7 sections, were less intensively hybridized to ascertain the genetic relationships among species of various sections and the limits of crossability between species.

Two major objectives motivate the *Mimulus* investigations. One of these is to determine through experimental means the evolutionary relations between species of distinct sections of the genus, between closely related species of the same section, and between ecological races of one species. The other objective is to ascertain the suitability of *Mimulus*, specifically the members of the *guttatus* complex, for experiments on ecological and physiological genetics. To this end some 110 selected individuals of races and hybrids of this complex were cloned and transplanted to the three altitudinal stations, and it is hoped that a few key individuals can be tested next spring in the controlled greenhouses of the Earhart Plant Research Laboratory of the California Institute of Technology. The two major objectives dovetail and supplement each other.

POA INVESTIGATIONS

The background of the range-grass breeding program, employing members of

the genus *Poa*, and aiming at both practical and basic scientific objectives, has been detailed in previous Year Books (cf. No. 46, 1946-1947, pp. 95-103). The purpose is to explore the possibilities of creating new species of range grass having new sets of qualities and suited to new environments, by combining the inheritances of existing species. It entails the production and study of hybrids between species belonging to different sections of the genus and from very contrasting environments. The parental species and many of the hybrids set most of their seed without fertilization, and thus reproduce as apomictic clones rather than through ordinary genetic segregation.

The *Poa* hybrids often had as one parent a wild strain obtained from the extensive collections in the Pullman Nursery of the U. S. Soil Conservation Service. From the beginning of these experiments we have received the wholehearted co-operation of the Soil Conservation Service through Dr. A. L. Hafenrichter, chief of the nursery division of the Pacific Coast Division, and members of the staff. Accordingly, the *Poa* hybrids are under test not only at the three altitudinal transplant stations of the Institution, but also in a series of nurseries of the Soil Conservation Service extending from southern California to northern Washington. The members of our staff are following the progress of the tests in the nurseries of the Service in addition to those at our own stations. The most extensive of these plantings are at the Pullman Nursery, where about 5000 individuals of some 70 different forms have been grown this year.

Intercontinental transplant experiments. The apomictic clones of *Poa* offer exceptional advantages for transplant experiments on a geographically widely extended scale because they can be propagated by seed. In response to a request for seed of

winter-active grasses, samples of the new *Poa* hybrids and their parental species were sent to Dr. J. W. Gregor, in charge of grass research, of the Scottish Society for Research in Plant Breeding, at Corstorphine, Edinburgh. More than 2000 individuals of 15 strains were grown in an experimental plot with 8 replications, and Dr. Gregor has supplied an analysis of detailed notes and measurements on these strains made throughout the season of 1948.

Dr. Clausen, who was in Europe in 1948 attending the Eighth International Congress of Genetics in Stockholm, had the opportunity of seeing this experiment and conferring with Dr. Gregor on the results. Plants that had come from places having warm summers and severe winters did not grow well in the cool, moist summer climate of Edinburgh, but plants from cool coastal regions made a better showing. The summer climate of Edinburgh is not duplicated at any of the other stations where these grasses are being tested, and it appears to bring out differences between those plants that require heat for their best growth (continental-type plants) and those that thrive under cool conditions (plants fitted for the west coasts of the continents). These characteristics are transmitted from the parents to their hybrids. In view of the favorable early results, it was decided to augment the experiment by testing additional strains and hybrids.

Through personal contacts made in Europe by Clausen it was also possible to arrange for a co-operative intercontinental transplant experiment on an extensive scale. The seeds were shipped to be sown in 1949, and the plants will be ready for measurement in 1950. About 40 largely apomictic species and hybrids of *Poa* are included in this experiment, and they are being tested in 13 environments that range from southern California, at 34° N., to

central Sweden, at 61° N., from sea level to 10,000 feet, and from coastal to continental climates, and that include various seasonal combinations of temperature and moisture.

The places at which these clones of *Poa* are now being tested and the collaborators in charge of them are as follows:

Western United States:

San Fernando, California, Dr. Paul Lemmon, Soil Conservation Service Nursery; coastal, 34° N. latitude.

Central California, Carnegie Institution stations, at sea level, 4600 feet, and 10,000 feet altitude, 38° N. latitude.

Pullman, Washington, Mr. John L. Schwendiman, Soil Conservation Service Nursery; continental, 2400 feet altitude, 46° N. latitude.

Bellingham, Washington, Mr. W. E. Chapin, Soil Conservation Service Nursery; coastal, 48° N. latitude.

Eastern United States:

Raleigh, North Carolina State College, Dr. Ben W. Smith; continental, 36° N. latitude.

Northern Europe:

Aberystwyth, Wales, Dr. T. J. Jenkin, Welsh Plant Breeding Station; very coastal, $52^{\circ} 30'$ N. latitude.

Edinburgh, Scotland, Dr. J. W. Gregor, Scottish Association for Research in Plant Breeding; coastal, 56° N. latitude.

Kapelle (Rotterdam), Holland, Dr. A. J. Th. Hendriksen, of D. J. van der Have, seed growers; subcoastal, 52° N. latitude.

Ötöftegaard, Denmark, Dr. H. N. Frandsen, Danish Associated Farmers and Co-operatives' Experiment Station; intermediate, $55^{\circ} 40'$ N. latitude.

Uppsala, Sweden, Dr. E. Åkerberg, Ultuna Branch of the Swedish Seed Association (Svalöf); continental, $59^{\circ} 50'$ N. latitude.

Volbu, Norway, Dr. Paul Solberg, State Experiment Station for the Mountain Districts, Løken; intermediate, 1500 feet altitude, 61° N. latitude.

Western Asia:

Seeds were earlier sent to Amman, Trans-jordan, Jubeiha Experiment Station (Mr. M. A. Haddad); continental, 3200 feet altitude, 32° N. latitude.

Each of these experiment stations is interested in discovering new plants for grazing purposes, and we are interested in determining the ranges of tolerance of the hybrids and their parents. These two objectives can be achieved through the experiment as planned, for the responses of each form indicate fairly accurately its range of tolerance, and each station is free to retain, multiply, or use for crossing any form that is well fitted for its own environment.

Two of the hybrids are intended for a selection experiment. They are sexual and therefore will segregate. In the very different climates of this experiment, selection will be made for the best strains. It would be of importance in the study of evolution to determine whether seeds of a single hybrid can give rise to new strains that fit contrasting climates.

Most of the stations have arranged to take brief notes on the performance of the plants through the various seasons, from which the seasonal periodicities of these forms can be determined. It is furthermore hoped that a member of our staff may be in a position to take more detailed and more fully comparable notes at a time when the plants are mature.

Physiology. As another step in this unique experiment, it is hoped that during the coming year key forms may be tested under controlled conditions in the green-houses of the California Institute of Technology, where Dr. Hiesey will co-operate with Dr. F. W. Went. Through these tests it should be possible to discover some of the environmental factors that determine the physiological responses of these *Poas* in various climates and to correlate the

responses with the heredities of the plants. Such tests will also indicate to what extent the experimental results under the controlled conditions of this unique new laboratory can be translated into predictable field performances in various climates.

Cytology. One other approach to the study of the *Poa*s included in the intercontinental experiment is through cytology. Dr. Grun is now studying the influence of the environment on chromosome distribution in selected clones of *Poa* in the transplant series of gardens, and it is hoped he will be able to study similarly the forms to be grown under the different controlled conditions at Pasadena. It is known that environmental conditions do affect chromosome pairing in some species. By using the cytologically unbalanced *Poa* species and hybrids, it may be possible to analyze further the patterns of environmental influences which cause variation in the behavior of chromosomes.

Embryology. Plants such as *Poa* that produce seed without fertilization can follow various methods in developing their seed, but how and where the asexual embryos arise can be determined only by detailed microscopic studies. Dr. Axel Nygren, of the Institute of Plant Systematics and Genetics of the Agricultural College of Uppsala, Sweden, who is making such studies on the embryology of European species and hybrids of *Poa*, expressed interest in studying our hybrids also. His request was welcomed, because such studies on the development of the embryo would complement Grun's investigation of the male sex cells of the same hybrids. Dr. Nordenskiöld prepared and shipped material for Dr. Nygren's preliminary studies while she was at our laboratory. Additional materials will be available to Dr. Nygren in the plot of the intercontinental transplant experiment at Dr. Åkerberg's neighboring institution in Uppsala, so that

these plants will serve a double purpose.

Genetic studies. Our understanding of the inheritance patterns in *Poa* has been advanced through the study of some 8000 F_2 and F_3 individuals at Stanford, in addition to the 5000 plants tabulated at Pullman. All together, 175 progenies have been analyzed. These represent offspring of 97 F_1 individuals from 22 different crossings and 9 kinds of interspecific hybrids, as listed in table 1.

All hybrids of which a sufficient number of progenies were grown produced not only apomictic but also sexual offspring in somewhat variable proportions. In all crossings but one, both parents were apomictic. In the exception, the paternal parent was sexual, but this combination produced at least as large a proportion of apomictic offspring as the others. Among 97 F_2 progenies, 43 were apomictic to a greater or less degree, and 54 were purely sexual, as listed in table 1. This proportion between apomicts and sexuals might suggest a very simple genetic formula for the inheritance of apomixis in *Poa*, but it is not so simple as that, for the apomictic F_1 individuals are apomictic to very different degrees. This is indicated by their F_2 's, in which the proportion of maternal-type offspring ranges from 10 to 90 per cent of the total.

The derived apomicts, in turn, produce asexual offspring of their own type and, in addition, aberrants which probably arise by means of the still active sexual process (table 1). This behavior resembles that of their naturally occurring apomictic parents. Unlike the parents, however, which produce weak aberrants that are quickly eliminated in competition, the derived apomicts may produce aberrants that are either stronger or weaker than themselves. Since some of these aberrants may, in turn, prove to be apomictic again, this source of

variation must be considered in breeding work.

A very vigorous, fertile, and adaptable apomict has arisen in this manner from a weak apomict hybrid of *Poa ampla* \times *pratensis alpigena*. The particular F_1 parent of this new apomict was itself apomictic, but it was a nonflowering dwarf at Stanford, though fairly vigorous at Mather and Timberline, where it ripens seed. Most of

south of the habitat of either of its grandparents. It is one of the apomicts now being tested in all the environments of the intercontinental transplant experiment.

Another promising apomict, developed from a sister F_1 of the *ampla* \times *pratensis alpigena* cross just mentioned, had quite a different history. This apomictic line was of an agriculturally highly desirable type, combining some of the best characters of

TABLE 1
NUMBER OF PROGENIES OF INTERSPECIFIC HYBRIDS OF POA

HYBRID COMBINATIONS	F ₁ PROGENIES		F ₂ PROGENIES				TOTALS
			FROM ABERRANTS IN APOMICTIC F ₁ S		FROM SEXUAL F ₁ S		
	Apomictic	Sexual	Apomictic	Sexual	Apomictic	Sexual	
<i>ampla</i> × <i>pratensis</i>	20	15	7	2	6	7	57
<i>ampla</i> × <i>compressa</i>	1	5			4	4	14
<i>ampla</i> × <i>arida</i>	1	1					2
<i>Canbyi</i> × <i>pratensis</i>		1				3	4
<i>scabrella</i> × <i>pratensis</i>	14	25		2	20	23	84
<i>scabrella</i> × <i>compressa</i>		1					1
<i>scabrella</i> × <i>arida</i>	2	1					3
<i>scabrella</i> × <i>ampla</i>	2	2					4
<i>scabrella</i> × <i>gracillima</i>	3	3					6
Totals	43	54	7	4	30	37	175
	97		11		67		

its offspring are uniformly weak and vegetative at Stanford like itself, but a few of its aberrants are vigorous and flower freely. One of these is the new apomict, which is both very fertile and highly apomictic. It is vigorous like *ampla*, rhizomatous like *alpigena*, rust-resistant, and apparently better adapted for contrasting climates than either parent of the original hybrid. This derivative of a plant from the Palouse Prairie in Washington and another from Lapland thrives at Stanford and also at the two mountain stations, at a latitude far

each parent. It was only 10 per cent fertile, however, and some of its aberrants were as vigorous as itself or even more so. In an attempt to produce a more fertile line, F_2 populations were grown from four of its best aberrants, which had presumably risen sexually. One of these was considerably improved over its F_1 parent. It is 70 per cent fertile—twice as fertile as its *ampla* grandparent—and it is 85 per cent apomictic, a proportion comparable with that found in wild Poas. Moreover, its aberrants are weak, so they will be eliminated

in competition with the vigorous apomictic type. In the gene exchange it also gained longer rhizomes, an advantage in many climates. These examples illustrate selection methods that can be applied in improving plants that already are apomictic.

The situation is different in the sexual fraction of the F_1 interspecific hybrids in *Poa*. They produce segregating, variable F_2 progenies. Tests on a series of individuals from such F_2 populations showed that some F_2 plants had become apomictic like the grandparents, but others had remained sexual. Among 67 F_3 progenies from sexual F_2 's, it was found that 30 were more or less apomictic and 37 were still sexual (table 1). The degree of apomixis in such F_3 's varies as in the apomictic F_2 progenies, a fact which suggests that the segregation for this characteristic is still fairly intricate. From the breeder's point of view it is most fortunate that a sexual period of recombination of genes or blocks of genes may intervene before the inflexible hereditary pattern of apomixis is regained.

An example of the effect of such recombination is afforded by a sexual hybrid out of *Poa scabrella* from coastal southern California \times *P. pratensis* from the Athabasca region of Canada. This sexual F_1 inherited winter activity and the bunchgrass habit from its *scabrella* parent, and increased tillering and slight summer activity from *pratensis*. Its periodicity limits it to environments with mild winters, where it outperforms its *scabrella* parent because of its longer period of activity. At Mather, where the winter is long and cold, it is forced into winter dormancy and is scarcely able to survive. A highly variable F_2 was grown from this plant at Stanford, all the individuals of which were winter-active. Four of the best F_2 plants, which had the longest rhizomes and were most summer-active, were selected for progeny tests. The best of these shows fertility in-

creased from 25 to 90 per cent, has long rhizomes, is active most of the summer, is apomictic, and survives the Mather winter successfully. This strain is also included in the intercontinental transplant experiment.

The apomictic, nonsegregating *Poa* progenies are on the whole much more vigorous than the sexual, segregating ones. Many of the variable offspring of the latter are so weak that they are unable to survive even in the experimental field. This difference in performance is understandable when we remember that these are hybrids between very distinct species. Each parental species has a balanced combination of genes selected in the long process of evolution. In different species, however, these balances are produced by different sets of genes. The F_1 hybrids have received an unbroken set of genes from each parental species, and in so far as these sets can produce a harmonious physiological development when together, the F_1 is successful. The apomictic offspring of the F_1 are also successful, for they actually represent an unaltered clone containing an intact chromosome set from each parental species.

By contrast, the offspring of the segregating, sexual sister hybrids arise from an exchange of genes. This causes great variation, because the offspring receive various proportions of the parental genes. Probably a number of the exchanged genes govern physiological processes that run counter to each other, as, for example, photosynthesis and respiration. If such processes become unbalanced, growth may be adversely affected. Many offspring of these sexual hybrids actually die in the seedling stage, and others make almost no growth or are very susceptible to disease. This is the same pattern of weak and diseased offspring already observed in many other interspecific hybrids previously investigated. Occasionally, however, a vigor-

ous, well adapted plant arises through such interspecific gene shuffling, and if that event coincides with the reinstitution of apomixis, a new apornictic species or an agronomically important new grass may appear.

Taxonomy of Poa. The experimental program has dealt with relatively few species in *Poa* and principally with the members of but two of its sections. In part because of the presence of incomplete apomixis, and in part because of a wealth of minor morphological characters that appear in a bewildering array of combinations, *Poa* is a highly variable genus, and the specific and even the sectional lines within it are rather indistinct. This has meant that a sound taxonomic treatment of *Poa* was required for presenting the experimental results.

Poa is of almost world-wide distribution, but for the present purpose Dr. Keck has made a systematic study of the 50 or so species occurring in the western United States, where it is the largest genus of grasses represented. The resulting treatment, which is helping to clarify the relationships in this complex group, has utilized the cytological and experimental results thus far available.

CALIFORNIA PLANT COMMUNITIES

Dr. Keck has been co-operating with Dr. P. A. Munz, of the Rancho Santa Ana Botanic Garden, on a classification of the plant communities in California as a prelude to the writing of a new type of regional flora for California. The plant communities reflect the climatic differences within a region in much the same way as do their component species and climatic races, a fact which suggests that similar environmental factors govern the distribution of all. The results of experiments on California plants are to be utilized in the writ-

ing of the manual, and, conversely, the preparation of the manual is a means of discovering groups of plants that are in need of experimental attention.

ARMERIA STUDIES

H. G. BAKER

The genus *Armeria*, the thrift or sea pink of the Plumbaginaceae, is almost restricted to Europe and the Mediterranean borders of North Africa. The only species which ranges outside this area is *A. maritima* (Mill.) Willd. The wide, discontinuous distribution of this species includes stations in northern Asia and North and South America, as well as in Europe. There is evidence which suggests that the disjunct nature of this distribution is connected with extensions and contractions of the range of the species during the Pleistocene epoch. These isolated populations form promising material for the study of local adaptation and of the relation of this to the particular breeding mechanisms that are found in *Armeria*.

Discontinuity in the distribution of *Armeria maritima* is particularly striking in North America. Here forms are scattered from Newfoundland and the Gaspé Peninsula through the Canadian and Alaskan Arctic, and along the Pacific coast as far south as southern California. A single, very isolated population of *A. maritima* var. *labradorica* Lawr. occurs at an altitude of about 12,000 feet on Hoosier Ridge in the Colorado Rockies, more than 1500 miles from the nearest known population of its closest relatives in the vicinity of Hudson Bay.

Apart from those in the far north, populations of each of the European forms of *Armeria maritima* contain balanced proportions of two kinds of plant, which appear to differ only in the morphology and physiology of their pollen and stigmata.

The flowers of one kind of plant bear stigmata that somewhat resemble miniature maize cobs, and anthers containing pollen grains (type A) with coarsely reticulate ornamentation. The stigmata of the other kind of plant are clearly papillate, and the pollen grains (type B) show an ornamentation of fine spines. Both kinds of plant are self-incompatible but cross-compatible, for type A pollen germinates only upon "papillate" stigmata, and type B pollen only upon "cob" stigmata. Such populations are said to be dimorphic.

The races which inhabit northern Norway and the Kola Peninsula, northern and northeastern Asia, and North and South America contain only one kind of plant and are therefore monomorphic. These plants have type A pollen and papillate stigmata, and are self-compatible.

More than 1500 individuals of *Armeria maritima* are being grown in a uniform garden and in the greenhouses for the purpose of analyzing their heritable differences and of correlating these with the environments from which they came. These represent 41 natural habitats in Europe, the Faeroes Islands, Iceland, Greenland, and North and South America, and include some of those which geographically are most disjunct.

Three major groups are recognizable in the cultures of this species. The first comprises the plants from western Europe. These are dimorphic, obligatorily outbreeding, with large, showy flowers, and their populations are very variable. Several distinctive races have developed in this group, and they occupy sea cliffs, pebble beaches, and salt marshes. Farther inland, they occur in high montane habitats and rarely in the lowlands. Within this group, populations from the Shetland and Faeroes Islands and Iceland in the North Atlantic may constitute a distinct oceanic racial complex.

The second group, inhabiting arctic Eurasia and northern North America, is composed of monomorphic, self-compatible plants that have small, inconspicuous flowers containing relatively few pollen grains. Within this group, var. *labradorica* Lawr. is in culture from localities ranging from the Gaspé Peninsula, through Labrador and by Hudson Bay, to Great Bear Lake in the Northwest Territories and the remarkably disjunct Colorado station, together with representatives of the more highly arctic var. *sibirica* Lawr. from Greenland.

The forms of the third major group of *A. maritima* inhabit the coasts of Pacific North America and northeastern Asia. They have conspicuous flowers like European races, but are monomorphic and self-compatible. They show less variation within populations than does the European dimorphic complex, although there may be considerable difference between populations. The plants from the north, from Puget Sound northward and westward along the coast to Alaska and Sakhalin, have, among other distinctive characters, ciliate leaves. They have been recognized as var. *purpurea* Lawr. Rarely in the Puget Sound area and more commonly southward to southern California, the populations usually have glabrous leaves and belong to var. *californica* Lawr. Unlike the European dimorphic members of this species, the members of this group have not evolved forms adapted to salt-marsh conditions or to alpine environments.

It is possible to intercross all the forms of *Armeria maritima* which have been cultivated, irrespective of their geographic origin. Such crossings are successful only when the appropriate kinds of pollen and stigmata are brought together, even when self-compatible and self-incompatible forms are being intercrossed. For example, pollen of the self-compatible race from the

California coast (type A/papillate) will germinate upon the stigmata of only one kind of the European self-incompatible var. *typica*, namely type B/papillate. On the other hand, the Californian form can be successfully pollinated only from the other European kind (type A/cob). Crossings already performed between European var. *typica* and Canadian var. *labradorica* suggest that the genetical determination of this breeding mechanism is relatively simple, and resembles that of dimorphic heterostyled genera such as *Primula*.

These rules apply also to the production of interspecific crosses. By following them, successful crossings have been achieved between *Armeria maritima* and each of the following species: *A. plantaginea* Willd., *A. canescens* Host., *A. pseudarmeria* Lawr., and *A. Welwitschii* Boiss. The last crossing is notable because it is intersectional and indicates that the boundaries of intercrossability may reach far into the genus.

In addition to these experiments, material for pollen analysis of the Plumbaginaceae was obtained in some of the major American herbaria.

INVESTIGATIONS IN THE GERANIACEAE

H. G. BAKER

Geranium. The section *Robertiana* of the genus *Geranium*, as defined by Knuth, is probably unnatural. Two of its species, however, *G. Robertianum* L. and *G. purpureum* Vill., are certainly quite closely related, and they have been the objects of this study. *Geranium purpureum* is diploid ($2n=32$) and strictly annual. Its distribution is essentially Mediterranean, although fingers reach through France to southwestern England and Ireland, and also into eastern Africa and Macaronesia. *Geranium Robertianum* is annual or biennial and is distributed widely through Europe (except in the north) and along

the mountain chains of Asia to China. Diploid forms ($2n=32$) have been found in the British Isles, but all forms examined from continental Europe are tetraploid ($2n=64$).

Seventeen representative forms of *G. Robertianum* from coastal and inland British populations, and 3 races of *purpureum*, have been in cultivation in Leeds, England, for periods up to 5 years. A dozen of the cultures of *Robertianum*, 3 of *purpureum*, and 7 of hybrid origin were planted in the garden at Stanford and have provided information concerning their performance in a completely different environment. A race of *Robertianum* from Ithaca, New York, which differs from any known in Europe, has been added to the cultures, and it is hoped to extend these further to include races from northern India. Further crosses have been made this year between races of both species, whereby it will be possible to study the genetic barriers between them.

Erodium. The abundance of plants of *Erodium*, the filaree, is particularly striking to a visitor in California, and some of the problems which they pose are very challenging.

Three species of this genus have long been known to be important members of the introduced flora of California and to have considerable value as forage plants. In all probability, *Erodium cicutarium* L'Her. reached California with early settlers from southern Europe, and was plentiful in the Central Valley by 1844. *Erodium botrys* Bertol. and *E. moschatum* L'Her. followed later. Until 1943, two distinct forms had been confused under the name *E. botrys*, and very recently one of them has been separated by J. T. Howell as *E. obtusiplicatum*. This form may have been introduced from North Africa.

Forms of these four species have been

grown, studied, and intercrossed, and, in addition, probable natural hybrids have been detected in a mixed natural population of *botrys* and *obtusiplicatum* on the Stanford campus. These putative hybrids appear to be fertile, although *botrys* and *obtusiplicatum* frequently occur together, and there appears to be little difference in their ecological requirements. There is

some evidence that the prevalent self-pollination of these species may account for the restricted amount of hybridization between them in many localities. Seed has been gathered for the cultivation of *E. cicutarium* from a series of habitats, which should give some indication of the part played by direct environmental modification in the polymorphism of this species.

PALEOBOTANY

RALPH W CHANEY

The nearest American relatives of the Chinese redwood, *Metasequoia glyptostroboides*, are *Taxodium distichum*, the swamp cypress, and *Sequoia sempervirens*, the coast redwood. Superficially similar in foliage and other characters, these two species differ fundamentally in their climatic and topographic requirements. The swamp cypress lives in regions of summer rainfall in the eastern United States, and is limited to lowlands, largely to river swamps. The coast redwood occupies areas with winter rainfall and summer drought, and is confined to the shores of the Pacific where summer fog is prevalent; primarily a tree of well-drained river flats, it is also abundant on valley slopes to an altitude of 3000 feet. *Taxodium distichum* ranges north into regions of continental climate, where there are wide seasonal extremes in temperature, with several cold winter months; *Sequoia sempervirens* does not live beyond the limits of a marine climate characterized by low daily and annual ranges in temperature, where freezing is seldom prolonged. In view of these differing regimes of rainfall and temperature, it is natural to find that the coast redwood has an evergreen habit whereas the swamp cypress is deciduous.

During the middle part of the Tertiary period, from twenty to forty million years

ago, fossil representatives of *Taxodium* and *Sequoia* were widely distributed over the western United States, as was the now Asiatic genus *Metasequoia*. In the John Day Basin, where the most complete sequence of Tertiary floras is to be found, *Metasequoia* was at the outset the most abundant of these conifers; at Twickenham its leafy shoots make up over three-fourths of the specimens recently collected, with katsura (*Cercidiphyllum*) and birch (*Betula*) also abundant; both these trees are modern associates of *Metasequoia* in central China. The gradually rising Cascade Range, which involved the piling up of lava flows and pyroclastics during this later Tertiary volcanic climax, appears to have altered the environment in eastern Oregon both as to climate and as to topography. Judging from the Miocene vegetation, this barrier to the west was at least partially responsible for reduced precipitation and greater extremes of temperature. With the blocking of streams, many lakes and swamps were formed. In the Dayville region, *Taxodium* was a predominant tree, together with oaks, hickory, and others now found living with it in the eastern United States. *Metasequoia* survived there in limited numbers, apparently in better-drained habitats on adjacent slopes. *Sequoia* is never found in direct association, but is well represented in volcanic

ash deposits of the near-by Blue Mountains, in association with other conifers and with angiosperms which suggest a higher elevation. Within a distance of forty miles there are Miocene records of the occurrence of these three genera of the Taxodiaceae, now widely scattered and in diverse habitats. The continued uplift of the Cascades and the consequent changes in environment on their eastward flanks have eliminated a majority of the Tertiary tree genera from the John Day Basin and from other interior localities in western North America. *Sequoia* was first restricted to the coastward slopes, where it ranged as far north as Portland during Pliocene time, and is now limited to the coast of southwestern Oregon and California. Current studies of its living conditions at the south end of its range, in Monterey County, suggest that if a trend toward drier climate were to continue into the future, the coast redwood might make its last stand in the coastal mountains of central California, in a habitat much like that which can be reconstructed for the region of last occurrence of Miocene redwoods in the John Day Basin.

With the change to a drier climate, *Taxodium* and many of its associates have disappeared from western North America. A study of its modern distribution in the southeastern United States, using funds made available by a grant from the American Philosophical Society, has yielded many significant data regarding the occurrence and associates of *Taxodium distichum* and is providing a basis for comparisons with the limited forests of *Metasequoia glyptostroboides* in central China. The rainfall regime there is the same, and the Chinese redwoods are likewise deciduous; but the mountainous setting introduces major differences which can be interpreted only after further field work has been completed. In view of the present unsettled

political situation, plans for work in China during 1949 have been postponed. Fortunately there was a continuation of field studies in the *Metasequoia* forest by Chinese botanists during the summer of 1948; there is now a basis for determining that this relict tree occupies a zone of ecological transition between the temperate forest of higher altitudes and the subtropical forest below. Additional collections from the Tertiary of Oregon and British Columbia, and extensive studies of material already available, are indicating that many of the fossil occurrences of *Metasequoia* in western America represent ecological transition zones similar to that in the mountains of Hupeh and Szechuan. This region will continue to provide critical data regarding Tertiary climate and topography, containing as it does one of the most significant forest survivals ever discovered.

Under the auspices of the Save-the-Redwoods League, and with the assistance of the University of California College of Agriculture, a large number of seedlings of *Metasequoia glyptostroboides* have been propagated. These are being distributed over a wide area in western North America, from southeastern Alaska to British Columbia along the coast, and at numerous localities at varying altitudes in western Washington, Oregon, and California. Seedlings have been sent also to Mexico and Guatemala, where they will be planted in upland areas now occupied by survivors of the Arcto-Tertiary Flora. This Flora, which appears to have had its origin in Alaska and other northern lands in Cretaceous, and early Tertiary time, formerly included *Metasequoia* as one of its most abundant members. The subsequent migration of this forest southward, and the gradual elimination of *Metasequoia* and other genera, is a matter of substantial record. It is now proposed to plant

Metasequoia wherever there are existing constituents of the Arcto-Tertiary Flora. In addition it will be replanted in as many of its localities of Tertiary occurrence as possible, leaving out—at least for the present—the areas east of the Cascades and Sierra Nevada where existing conditions are now too arid to offer much hope for the growth of a tree with such high moisture requirements. At this time there is no basis for confidence that the redwood of Asia will survive Alaska winters, though its deciduous habit carried it through the exceptionally cold winter of 1948-1949 as far north as Portland, Oregon. In any event we shall gradually learn whether the factors which resulted in the extinction of *Metasequoia* in North America during

later Tertiary time are still operating, or whether this tree may again become a resident of a continent from which it disappeared some fifteen million years ago.

Dr. Daniel I. Axelrod has continued his study of Pliocene floras of Nevada and California. Several of these represent vegetation of a more arid type than is elsewhere found in the fossil record of North America. As a result of these investigations, knowledge of the origin and relations of desert and steppe vegetation is being greatly enlarged. A group of papers by Dr. Axelrod under the general title "Studies in Late Tertiary Paleobotany" has been approved for publication by the Carnegie Institution in its Contributions to Paleontology.

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DEPARTMENT OF EMBRYOLOGY

Baltimore, Maryland

GEORGE W. CORNER, *Director*

The Department of Embryology continued its work during the year without serious interruptions or distractions. Changes in the group were few. Mrs. Faith Wilson LaVelle, Fellow of the American Association of University Women, left the laboratory in July 1948, having practically completed her research project under the direction of Dr. R. K. Burns. She received the degree of Doctor of Philosophy from Johns Hopkins University in June 1949, offering a thesis based on her work in this Department, which will be published in the Contributions to Embryology. Dr. Jerome S. Harris was appointed to a fellowship of the Carnegie Institution, which he relinquished for part of the year to serve as intern in obstetrics in the Johns Hopkins Hospital. Dr. Edward C. Gillespie came following an internship in the Johns Hopkins Hospital, Department of Obstetrics, to spend a year in research with Dr. S. R. M. Reynolds. Dr. Charles L. Schneider, of Wayne University Medical School, Detroit, came for several months for the same purpose. Dr. Jorgen U. Schlegel, a member of the Department of Anatomy of the University of Copenhagen, spent the year on a fel-

lowship of the Rockefeller Foundation. Dr. R. Mahanti, Professor of Anatomy at Orissa University, Cuttack, Hindustan, was guest of the Department for several months, observing technical procedures and studying research problems. Professor M. H. Toosy, of the Medical School at Lahore, came for four months by request of the Embassy of Pakistan. Dr. E. Carl Sensenig, Associate Professor of Anatomy in the Medical College of Alabama, again worked in the Department in the summer of 1948. Dr. L. J. Wells, Associate Professor of Anatomy in the University of Minnesota, returned for several weeks early in 1948 to complete the preparation of a monograph on the development of the human diaphragm begun during his tenure of a Guggenheim Fellowship in the Department in 1946-1947. Toward the end of the period of this report, Dr. Árpád Csapó, an experienced pupil of Professor Szent-Györgyi in the biochemistry of muscular tissues, arrived from Budapest via Sweden to be a fellow of the Carnegie Institution and to work in consultation with Dr. Reynolds and Dr. Corner on the physiology of uterine muscle.

PROGRAM OF INVESTIGATIONS

Morphology and experimental embryology. Dr. C. H. Heuser, Curator of the Embryological Collection, prepared during the year about a dozen valuable early human embryos in serial sections for addition to the collection. He continued his studies on the morphology of early human and baboon embryos, with special regard to the formation of the yolk sac. Dr.

Heuser also devoted much time to the task of preparing for press an article ("Developmental horizons in human embryos," stages xix to xxiii) which was left unfinished by Dr. G. L. Streeter at the time of his death.

Under Dr. Heuser's direction Dr. M. H. Toosy continued the study of an interesting double monster, one of the earliest

known specimens of this anomaly in man.

Dr. R. K. Burns devoted his time during the year to the completion of two extensive review articles on the embryonic differentiation of the reproductive tract in vertebrates, and to supervising the preparation for publication of papers by Dr. Faith Wilson LaVelle (on the development and response to hormones of the reproductive tract of the hamster) and Robert J. Faulconer (on the embryology of the ostium of the Müllerian duct in man).

Dr. Joseph Gillman, Research Associate, Johannesburg, South Africa, persisted in his efforts to obtain very early baboon embryos of known age. The difficulties and uncertainties familiar to workers in this field are such that the youngest baboon embryo yet obtained for the Collection by Dr. Gillman is 13 days old. Efforts to obtain the critical stage of 10-11 days are being continued.

Dr. Elizabeth M. Ramsey, following the completion of her studies on the uterine vessels of the rhesus monkey in pregnancy (see below under "Published research") began intensive study of the same problem in man. Through the co-operation of the Department of Obstetrics of Johns Hopkins Hospital, several pregnant human uteri have been sent in directly from the operating room and have been injected by Dr. Corner with India ink through the uterine arteries. These valuable specimens, to which additions may be expected from time to time, have been placed at the disposal of Dr. Ramsey.

Dr. J. U. Schlegel was occupied during the year in perfecting a technique for the demonstration of blood and lymph vessels by the use of an injected dyestuff which stains the endothelial lining of the vessels while it is passing through their walls. The substance used is fluorescent and thus becomes visible in ultraviolet light, so that the vessels are seen as shining channels in

otherwise unstained tissues. The method is aimed at demonstrating the arterio-venous anastomoses in the endometrium recently described on the basis of observations by other methods, by Schlegel, Dalggaard, and Okkels at Copenhagen. It offers also a ready means of determining the time necessary for the passage of the solution of dyestuff from the blood into the lymph stream. The method was described in a preliminary report at the 1949 meeting of the American Association of Anatomists.

Mrs. Dorcas H. Padget made further progress during the year on her studies of the development of the cerebral veins, begun several years ago under a grant to Dr. Corner from the Life Insurance Research Foundation.

Dr. E. Carl Sensenig during his annual summer visit made an investigation of the early development of the spinal meninges in the human embryo, and presented a preliminary report on this subject at the 1949 meeting of the American Association of Anatomists.

Very early human embryos and associated corpora lutea. Dr. Arthur T. Hertig, Research Associate, has actively continued the program of collection of human embryos in association with Dr. John Rock, and with the co-operation of Dr. William J. Mulligan and Dr. F. A. Pemberton, at the Free Hospital for Women, Brookline, Massachusetts and the Boston Lying-in Hospital. During the year, uteri and oviducts from 17 fertile patients subjected to hysterectomy for various reasons, and for whom one or more coital dates were recorded at about the presumed time of ovulation before the operation, were searched. Four embryos were recovered, three of which are of extremely early age. All these are now in the collection of the Department of Embryology, as follows:

No. 8698. A dividing ovum in the 2-cell stage. This is the youngest human em-

bryo, developing under normal circumstances, ever seen. The specimen was recovered from the oviduct at operation 60 hours after coitus. An ovary with the corpus luteum was also removed. Dr. Hertig estimates the endometrium as of the early part of day 17 of the standard cycle, i.e., day 3 after ovulation. (A closely similar 2-cell egg, inseminated and cleaved in vitro in the laboratory of Dr. John Rock in Boston, is also in the Carnegie Collection; see Year Book No. 47, 1947-1948, p. 117.) Dr. Corner estimates the corpus luteum as about 48 hours old. The two symmetrical blastomeres of this wonderful specimen are enclosed in the zona pellucida. One polar body is clearly visible, the other if present is obscured. The specimen has been adequately photographed and will be cut into serial sections by Dr. Heuser.

No. 8630. An abnormal 5-cell segmenting ovum from the cavity of a uterus corresponding to day 19 of the standard cycle, or about day 5 after ovulation. The blastomeres are multinuclear and show other evidences of abnormality and delayed development.

No. 8663. A normal blastocyst from the cavity of a uterus corresponding to day 19 of the standard cycle or about day 5 after ovulation. This is the second youngest known normal human embryo at present writing. The specimen, which is probably a little shrunken, measures 0.134 by 0.115 mm. and has a cavity 0.057 mm. in diameter. It closely resembles the embryos of other mammals at a similar stage of development. There is an inner cell mass composed of 15 or 20 cells. The rest of the blastocyst wall is composed of a single layer of large cells. It has been perfectly sectioned by Dr. Heuser.

No. 8672. A 13-day ovum measuring 2.34 mm. in diameter, implanted on the posterior wall of the left lateral sulcus of

the uterine cavity. The tissues of this specimen, in the embryonic disk as well as in the trophoblast, are in poor cytological condition, and the chromatin of mitotic figures in dividing cells is clumped. The embryo was probably dying. It shows early unbranched chorionic villi, a bilaminar germ disk, and an early definitive yolk sac which has been formed by an hourglass constriction of the large space enclosed within "Heuser's membrane" (coelomic or exocoelomic membrane of various authors). In this respect the specimen sheds light on the problem of the peculiar origin of the yolk sac in man, long debated in this laboratory and by those outside it who have followed the advancing knowledge gained from the Hertig-Rock and other early human embryos.

The corpus luteum. Dr. Hertig reports that the work on the histology and histochemistry of the corpus luteum of pregnancy, referred to in the last Year Book, has been carried on during the year by himself, Mr. Roger F. White, Dr. John Rock, and Miss Eleanor C. Adams and will soon be ready for publication. About 40 selected human corpora lutea of pregnancy and 50 nonpregnant specimens have been used.

Dr. John Rock, of the Free Hospital for Women, Brookline, Massachusetts, has continued to give his advice and help in the program of collection of early embryos. His own studies on living human eggs are made in association with that program, though supported by other organizations, chiefly the American Cancer Society through the Committee on Growth of the National Research Council. He reports having recovered 158 human ova from 49 patients; 123 ova were inseminated in vitro and cultured for 48 hours in serum. Three of these eggs divided in vitro, two of them reaching the stage of 2 blastomeres and one of them dividing into 3 blastomeres.

Two patients received pituitary extract treatment before the ovaries were removed. Their ovaries yielded 9 ova, recovered from follicles over 1 cm. in diameter, all containing spindles of the second polar division, as do fully mature follicular ova in most mammals that have been studied. It appears that these ova were caused to mature by the pituitary extract.

Embryonic pathology. In recent years it has become known that one of the common contagious fevers, rubella or German measles, a disease which is of trivial concern to the patient, may be the cause of dire consequences when the patient is a woman who happens to be in the first 2½ months of pregnancy. In such a case the infant is frequently born blind, with congenital cataracts, often with abnormally small eyes (microphthalmos), and sometimes even with microcephaly and mental retardation. Congenital deafness and anatomical abnormalities of the heart may also occur. Some infants of mothers who acquire German measles at the stated period of gestation may no doubt escape damage, and possibly there is a difference in the virulence of epidemics. At any rate, the discovery of this hitherto unsuspected relationship has caused so much concern among physicians that some of them have advised the termination of pregnancy when the mother has had German measles early in gestation. The Department of Embryology has received three fetuses from such preventive abortions, and has been entrusted with the preliminary study of two more from another laboratory. Dr. Corner and Dr. Heuser have undertaken the investigation of these specimens. The examination will be laborious and may for various technical reasons yield little information, but the gravity of the problem seems to make it a duty to see what can be learned from these fetuses.

Physiology of the uterus. Dr. S. R. M.

Reynolds and a group of fellow investigators have been at work on various problems in the physiology of the uterus, making particular use of the tokodynamometer, to which reference has been made in recent reports. Dr. Reynolds himself put a good deal of effort, with members of the Johns Hopkins Hospital obstetrics staff, into testing improved models of the tokodynamometer looking to a design suitable for wide practical use. He and the clinical observers have begun to use the instrument in a comparative study of the uterine factors involved in the induction of labor by the use of various oxytocic drugs. With Dr. Louis M. Hellman and Dr. Bruce A. Harris of the Hospital staff, he has completed the collection and analysis of data on the first stage of labor, which show the step-by-step development of the expulsive muscular force of the parturient uterus and the developing dominance of the fundus. Dr. Hellman has employed the tokodynamometer in studying the effects of pituitrin given during labor, with a view not only to explanation of its action, but also to improvement in the practical use of pituitrin in labor.

Dr. Reynolds has given much thought to the problem of the mechanical factors involved in maintaining the circulation of blood through the umbilical cord from the placenta to the fetus. Inasmuch as the anatomical structure of the umbilical cord is an important element in the problem, an anatomicophysiological study of the cord has been begun, in which the structure and relative size of the fully distended umbilical vessels will be studied, together with the status and function of "Wharton's jelly," the connective tissue of the umbilical cord. An extensive program of research on this important and hitherto neglected phase of the fetal circulation is planned.

Dr. Jerome S. Harris, working with Dr. Reynolds and Dr. Edward C. Gillespie,

completed a study of the changing form of the human uterus as it enlarges during pregnancy. Using repeated X-ray pictures, he observed two phases of the development of the gravid uterus. Until the 20th week of gestation, growth occurs in all three dimensions, but thereafter little growth occurs in thickness, and after the 30th week the width actually diminishes, and enlargement continues in length only. Dr. J. Tyler Baker, of Easton, Maryland, in the past a frequent contributor of embryonic material to the laboratory, was influenced by Dr. Reynolds' publications to compile a large series of direct measurements of the enlarging uterus obtained with obstetrical calipers. Though his data are not so precise in individual cases as measurements from X-rays, the large number of cases permits statistical treatment. The results of detailed analysis agree with Gillespie's data in showing that the 7th month is a critical time with respect to the provision of space in the uterus and favorable conditions of uterine blood circulation for the infant.

Dr. Gillespie also undertook experimental studies on the effect of alloxan diabetes on sexual receptivity in rabbits, on fertility, and on the growth of the uterus and the fetuses.

Dr. Charles L. Schneider spent a few months observing the work of Dr. Reynolds' group and conducting experiments on the experimental production of toxemic conditions in pregnant rabbits.

Mrs. Lyla T. Bradin continued her studies, previously reported, on the relation between the length of the phases of gestation in different species and the relative maturity of the fetus at birth. A preliminary report on the times of appearance of the various ossification centers in a number of small animal species, with respect to the rate of growth and the changing form of the uterus, was presented

at the 1949 meeting of the American Association of Anatomists.

General physiology of the embryo. Dr. Louis B. Flexner and his associates made further progress during the year in their program of correlating the physiological with the morphological development of the embryonic tissues. With Virginia B. Peters, Dr. Flexner studied the growth in volume of the nerve cells of the brain cortex (of the guinea pig) and the relation of the volume of the cell to that of its elements, the nucleus and cytoplasm, taken separately. By such observations a critical period of change in the development of the guinea pig's brain cortex is found to occur at the 41st to the 45th day of gestation. Dr. Leonard Gallant, of the Henry Phipps Psychiatric Clinic, Johns Hopkins Hospital, and Dr. David B. Tyler, working with Dr. Flexner, find that electrical activity of the cortex first occurs at about the same time.

Dr. Josefa B. Flexner and Dr. Louis Flexner are studying the permeability of the cerebral blood vessels to sodium and its changes during development of the fetal brain.

Dr. David B. Tyler has been investigating the enzyme systems that effectuate metabolic processes, particularly those concerned with carbohydrate metabolism, in the fetal brain, and the changes in their activity during development. He is applying to fetal tissue (rat's brain) the method usual in such work on adult tissues, i.e. that of counteracting the various enzyme systems in the tissues by the use of chemical substances known to interfere with the action of specific enzymes. Striking quantitative differences in the sequence of the chemical steps in the metabolism of carbohydrates, occurring at different stages of development, are thus being observed and subjected to interpretation with the aim of locating the sites of action of the metabolic

enzymes and the history of their differentiation in the embryonic tissues.

Co-operative activities. Some of the more extensive co-operative activities of the Department have already been referred to, namely, Dr. Heuser's study of early human embryology in association with Dr. Hertig and Dr. Rock, and the joint work of Dr. Reynolds and associates with the Department of Obstetrics of Johns Hopkins Hospital. Dr. Roger B. Scott, of the Department of Gynecology, Johns Hopkins Hospital, continued to use the monkey colony and operating-room facilities in his experimental studies on the production of endometriosis.

One of the most important co-operative services of the Department of Embryology has not been specifically mentioned in recent reports, though it continues unceasingly. This is the examination of specimens sent in by physicians, mostly abortive embryos and fetuses which come with urgent requests for information as to the cause of death or of abnormalities, the age of gestation when aborted, and other questions, some answerable and some unanswerable at the present stage of knowledge. This work is carried on chiefly

by Dr. Heuser, and to a less extent by Dr. Corner. In addition to the specimens sent for such study, there are frequent requests for information on matters concerning human and animal embryology and concerning the physiology of the reproductive system and its disorders.

Dr. Corner is acting as general adviser and consultant to the American Academy of Ophthalmology in the planning and preparation of a motion-picture film explaining the embryology of the human eye. Dr. George K. Smelser, of Columbia University, has been made a welcome guest of the laboratory in order to facilitate his work as technical adviser on the film.

In April 1949 Dr. Lawson Wilkins, of the Department of Pediatrics, Johns Hopkins Medical School and Hospital, gave two talks at the Department of Embryology on developmental and functional disturbances resulting from sex hormone deficiencies in human subjects. In June Dr. Alfred Yost, of the Collège de France, spoke at the laboratory on his experimental researches on the relation of the sex hormones to embryonic differentiation of the reproductive system.

PUBLISHED RESEARCH

HUMAN EMBRYOS OF EIGHT AND NINE DAYS

In Year Book No. 42, for the year 1942-1943, mention was made of the acquisition, through Drs. Arthur T. Hertig and John Rock, of two human embryos, nos. 8155 and 8171, thought to be about 8 and 9 days old respectively. These specimens were in due course successfully sectioned by Dr. Heuser and the sections were photographed by Mr. Heard for subsequent reconstruction on plastic sheets by Miss Eleanor C. Adams under Dr. Hertig's supervision in Boston. A detailed account of the two specimens has now been pub-

lished in the Contributions to Embryology, volume 33. These two specimens represent the stage of human development when the ovum has become well implanted and the uteroplacental circulation is just beginning to be organized. In the 8-day ovum, definitive trophoblast of both types is actively forming, and in the 9-day specimen further differentiation of the syncytiotrophoblast has resulted in the formation of a network of lacunar spaces for the reception of a small amount of stagnant maternal blood from enlarging capillary sinusoids eroded by the invading trophoblast. The embryo

in each of these ova is a bilaminar germ disk without axial differentiation. Amniogenesis has barely begun in the 8-day ovum, but is well advanced in the 9-day specimen. The so-called exocoelomic membrane ("Heuser's membrane"), which is not yet formed in the 8-day specimen, is present in the elder ovum and is described as being delaminated from the adjacent cytotrophoblast.

The two specimens here described lie between the 7-day and 9-day specimens described by the same authors in 1945 (Carnegie nos. 8020, 8004). The two younger specimens have solid trophoblast, but the two 9-day ova show stages of lacuna formation. The four present all the essential stages in amniogenesis, which consists in the progressive *in situ* delamination of amniogenic cells from the cytotrophoblast dorsal to the germ disk.

EMBRYOLOGY OF THE SKELETON; HISTOGENESIS OF CARTILAGE AND BONE

The late George L. Streeter was preparing, at the time of his death in July 1948, another section of his series of "horizons" or classificatory stages of human embryogenesis. This section was to cover horizons xix to xxiii, that is to say, the last phases of the embryonic period, as distinguished by Streeter from the fetal period of development. It was his intention to trace certain features of the development of each major organ system through the five horizons, and he had already prepared for publication a special article (see bibliography) on the histogenesis of cartilage and bone, in which he used the embryonic humerus as an index of differentiation. The following extract from Dr. Streeter's own summary will serve to indicate his line of thought:

"By confining attention to one bone and following it in all its stages one obtains a

more complete history of the consecutive factors that play a part in the development of the skeletal system. . . .

"In studying the humerus during its cartilaginous period, it was found that cartilage cells, as they grow older, pass through an orderly series of transformations. These include proliferation and growth of the cells, a characteristic vacuolization of their cytoplasm, formation and increase in amount and character of the intercellular substance, and terminal liquefaction or disintegration of the cells. By dividing these consecutive transformations into five arbitrary phases, it was possible to plot maps of the humerus showing the areas of distribution of the respective phases of cartilage that characterize the bone as it increases in size.

"It was found that there is always a growth center in the shaft in which the oldest cartilage cells are located. Adjoining it, above and below, are zones of successively younger phases, the youngest always at the ends of the bone.

"When the cells at the growth center reach the terminal phase of disintegration, the cells of the inner coat of the periosteum penetrate the primary osseous shell and make their way into the cartilage, which is thereon abruptly transformed into marrow.

"The time when this invasion occurs is arbitrarily adopted as the conclusion of the embryonic and the beginning of the fetal period of prenatal life. It occurs in specimens about 30 mm. in length."

EARLY DEVELOPMENT OF THE HUMAN VERTEBRAL COLUMN

The early development of the human vertebral column, and indeed of the mammalian spine in general, has received very little attention. Later stages of human development, after the appearance of car-

tilage and during ossification, have been more thoroughly studied, and the osseous stage has been extensively investigated particularly by roentgenologists, who need to understand the adult details and congenital anomalies seen in their diagnostic films. This situation has resulted in much confusion of description and terminology through the attempt to designate embryonic structures which are not fully understood or well defined, with reference to the adult structures of which they are forerunners. Dr. E. Carl Sensenig, now of the Medical College of Alabama, came to the Department of Embryology in 1944 on a special grant from the Carnegie Institution for the purpose of reinvestigating the early development of the vertebral column. His work was aided in several subsequent summers by the Joseph Henry Fund of the National Academy of Sciences. Results of the investigation appear in volume 33 of the Contributions to Embryology.

The embryology of the vertebrae is a very complicated matter, as might be expected in view of the peculiar demands upon the vertebral column for a combination of strength in protection of the spinal cord and in support of the body with flexibility in movement, firm anchorage for the ribs, and safe exit for the spinal nerves. The development of the individual units of this structure is indeed so complex that it baffles any attempt to discuss it in non-technical terms. For this reason it is impossible in a report intended largely for nonbiological readers to summarize the admirable monograph of Dr. Sensenig. It must suffice to say that he gives a carefully detailed description of the earliest mesoblastic (embryonic connective) tissue and its division into the primitive somites or sclerotomes. Each sclerotome is divided into a cranial and a caudal half by the appearance of a sclerotomal fissure through

the somite. Each of the vertebrae is formed (roughly speaking) by the fusion of the caudal half of one somite and the cranial half of the next tailward somite. This much has been known, for the vertebrates in general, since the description of Remak in 1855. Dr. Sensenig now fills in the details for the human species. Technical readers must study his work for themselves. They will note that he discards elaborate classifications of the stages of vertebral development because of the great overlap between successive periods, and finds that three periods, those of formation of membranous tissue, cartilage, and bone, suffice for descriptive purposes. He has not been able to trace the development of the nucleus pulposus with certainty, but leans to Luschka's theory of origin from the notochord.

Dr. Sensenig's observations on the origin of the ribs disagree with the reports of previous authors except von Bochmann, in that he finds that the caudal sclerotome-half as well as the cranial half contributes tissue to the developing rib. Part of the capitulum of the human rib is found to arise from the preceding vertebral segment. The same is true of the anterior zygapophysis of the vertebra. Sensenig states, contrary to the views of previous writers, that the early embryonic plane of separation between vertebral rudiments is not represented in the adult by the mid-point of the vertebral disk, but rather by the caudal surface of the disk where it articulates with the centrum or body of the vertebra. He gives a detailed account of the myocoeles (cavities of the somites), showing that in man they do not regularly connect with the coelomic cavity.

Two types of chondrification in vertebral development are described. In one type, which is slightly earlier in appearance, cartilage formation occurs directly in the loose areas of the primitive centrum. In other

parts of the vertebra, chondrification passes through a typical precartilagel stage.

EMBRYOLOGY OF DEFECTS OF KIDNEYS AND URETER

Variations in the number and arrangement of the ureters, with or without associated abnormalities of the form of the kidneys, are not unusual in adult human subjects. Because they offer a variety of difficulties when encountered in the diagnostic clinic and the operating room, a voluminous clinical literature has grown up on the subject. The embryological development of an anatomical anomaly, when it can be ascertained, often makes the adult conditions more comprehensible. Such anomalies are rarely seen in the embryonic stage, however, for the number of embryos subjected to detailed study is infinitely smaller than the number of persons examined by physicians. The Carnegie Collection contains one early embryo (no. 6516, 9.6 mm. CRL) in which a double ureter is developing on one side of the body. After the study of this specimen was begun by Dr. Lawrence H. Wharton, Jr., while he was a student in Johns Hopkins Medical School, Professor Sidney I. Kornhauser, of Louisville, Kentucky, very kindly made available another embryo (HgS of the University of Louisville collection). These specimens are among the youngest thus far reported that exhibit anomalies of the ureter. In the Baltimore embryo the left ureter is duplicated, and there are two renal blastemata (early kidney-forming tissue masses) corresponding to the two left ureters. The Louisville specimen has developed an accessory rudimentary ureteric bud on the right side, anterior to a normally located ureter and blastema. Although the factors which caused these variations from the normal cannot be established without a larger

series of cases, and indeed probably not without experiments on embryos of other more available species, the specimens described by Dr. Wharton bring out the fact that the formation of a normal kidney depends upon the occurrence of certain critical conditions in time and space, beginning with the formation of a normal mesonephric duct which gives rise to a normally situated ureteric bud. During this same period, the metanephrogenic condensation must be organized locally, and the bud must make contact with it to initiate further differentiation of the blastema, which in turn stimulates formation of the primitive collecting system from the pelvic part of the ureteric bud. Thus there are many opportunities for one or another failure of growth in rate or pattern, which may cause fundamental anomalies of the urinary organs.

ATRESIA OF THE OVARIAN FOLLICLE

In the ovaries of mammals many more egg-containing follicles are formed than can be used in the whole reproductive life of the individual female. The ovaries therefore contain at all times a number of follicles that are being obliterated before they reach maturity. The process of regression, which is called atresia, consists (generally speaking) in loss of the egg cell and the lining of granulosa cells, and in proliferation of the connective-tissue elements of the theca interna and theca externa until the cavity is obliterated. In the case of large follicles, absorption of the fluid and consequent shrinkage assists in the reduction of volume. The process of atresia differs considerably in detail from one species to another. For this reason it is useful to have a description of it as it occurs in a primate species. Little is known of the rate at which atresia takes place, or of its timing with respect to the ovulation cycle.

Dr. Somers H. Sturgis, now of Massachusetts General Hospital, undertook a study of atresia in the rhesus monkey while at the Department of Embryology in 1942 on a Rockefeller Fellowship which was interrupted by the war. Dr. Corner's collection of rhesus ovaries of known reproductive history, in complete serial section, was placed at his disposal. Sturgis begins his account by describing and illustrating three successive stages of atresia: The first is characterized by dissolution of the granulosa; the second ends with loss of identity of the egg cell, with full development of a zone of hyaloid tissue from the theca interna; and the third progresses to disappearance of all distinctive elements.

Sturgis was able to form an idea of the rate at which atresia proceeds by the study of certain peculiar examples of atresia occurring in small follicles that were partially luteinized. In other words, at the time when a normal mature follicle ruptured and was converted into a corpus luteum, a small follicle in the same animal responded by some chance to the same hormonal influences that were affecting the large follicle, so that while part of its wall was undergoing atretic changes, another part was converted into corpus luteum tissue. The atretic process could thus be tentatively dated from the cyclic history and from the corpus luteum tissue of determinable age. Sturgis concludes from his 3 specimens of partially luteinized atretic follicles that stage 1 of atresia probably develops in 24 to 48 hours, and is certainly over in 5 days; stage 2 requires about 3 weeks. The follicle then gradually regresses and probably reaches the terminal phase of relative quiescence in about 5 weeks after the initiation of atretic changes. These estimates refer to atresia beginning about the time of ovulation and may not apply to the speed of the retrogressive

process under other circumstances. Evidence is presented showing that atresia of relatively large follicles starts just before ovulation, probably serving thus to prevent multiple ovulation in animals which, like rhesus, normally shed only one ovum at a time. The theca interna of these degenerating follicles appears to function for only a few days just before and just after ovulation. Sturgis conjectures that such activity may augment the production of estrogen at a time when that hormone is necessary for ovulation and for luteinization of the follicle that is destined to rupture.

THE CERVICAL MUCOSA OF THE RHESUS MONKEY

The exit canal of the uterus (cervix uteri) is very important in reproductive physiology, for through it the sperm cells must travel inward and subsequently the infant must pass outward at the time of birth. It guards the entrance of a passageway that opens ultimately into the peritoneal cavity, which must be barred against invading microorganisms while permitting the entrance of the sperm and the exit of uterine secretions and (in menstruating animals) the catamenial flow. For these various functions the lining of the cervix must be adaptable to changing physiological needs.

Dr. Clara E. Hamilton's article in volume 33 of the Contributions to Embryology describes the changes in the epithelial lining of the monkey's cervix uteri in the ovulation cycle, in pregnancy, in castrated and amenorrheic animals, and under various experimental conditions of hormone administration. The work was done at the University of Illinois under the direction of Dr. Carl G. Hartman, member of the Department of Embryology from 1923 to 1941. Although Dr. Hamilton's work was extramural as regards the Carnegie labora-

tory, her material came chiefly from Dr. Hartman's and Dr. Corner's collections.

The observations deal with the cellular morphology of the epithelium (height, position of nuclei, content of mucus, regression, and secretion). It was found that the cell height is increased by estrogen, whereas sudden drops in estrogen level cause secretory changes and subsequent regression of the epithelium of the canal and the cervical glands. No inhibition of the effect of estrogen on the cervix by progesterone or testosterone was found with the doses used. Progesterone but not testosterone enhances the mucus content of the cells. In the light of these findings, the characteristic changes of the cervical epithelium in the ovulatory cycle, pregnancy, and castration are explained.

BLOOD VESSELS OF THE PREGNANT UTERUS

This year saw the culmination of a laborious program of research, marked by the publication, in volume 33 of the *Contributions to Embryology*, of Dr. Elizabeth M. Ramsey's monograph on the vascular pattern of the endometrium of the pregnant rhesus monkey. It has long been evident that the blood vessels of the uterus, and particularly those of its endometrial lining, undergo highly important changes during pregnancy. The peculiar coiling of the arteries of the human endometrium, first noticed by William Hunter in 1774, which is found also in the Old World monkeys, has aroused great curiosity as to its possible usefulness in the implantation of the embryo and the subsequent development of the placenta. Peculiar problems are also presented by the endometrial veins, with respect to the source of nourishment of the implanting embryo. The pathways by which the menstrual blood leaves the intervillous space of the placenta have been much discussed, though without full agreement by the various investigators.

Dr. Ramsey therefore began some years ago, at the suggestion of Dr. Carl G. Hartman, an ambitious attempt to study and describe the vessels of the endometrium and the maternal part of the placenta in the rhesus monkey in order to provide a sequential account of their functional changes throughout pregnancy. In all, 13 female rhesus monkeys were bred to secure a series of pregnancies of known dates. At the chosen time in pregnancy each animal was anesthetized and the blood vessels of the uterus were injected with India ink or other injection mass. Serial sections of large blocks from the implantation sites were made, and the blood vessels and other relevant structures were painstakingly modeled by Dr. Ramsey, using the technique of serial reconstruction on transparent plastic sheets. This project illustrates the effective way in which a specialized research laboratory can deal with certain kinds of work requiring organized co-operation, for it has demanded not only Dr. Ramsey's skillful and persistent efforts, but so much expert service of the departmental staff, from the breeding of the animals through the injecting and sectioning of the uteri to the illustration of the final publication, that a list of those who contributed special skills in furtherance of Dr. Ramsey's research would be almost a list of the whole personnel.

The monograph must be read and the illustrations must be studied to gain an idea of the instructive findings of the research. Summarizing briefly, the coiled arteries are found at first to become more coiled at the implantation site, but afterward to become extended and straight. This uncoiling, which takes place at the beginning of the last third of pregnancy, coincides with the end of the period of uterine growth and the commencement of the period of stretching without growth

that has recently been investigated by Reynolds (see this and recent Year Books). At the same time, the number of arteries connecting with the intervillous space decreases.

The spiral arteries of the placenta undergo a very peculiar change early in pregnancy, by which their endothelial lining becomes greatly thickened by increase of its cells. Dr. Ramsey devotes much attention to this phenomenon, arriving at the conclusion that the proliferation of lining cells is truly a proliferation of endothelium, rather than an invasion by cytotrophoblast cells of fetal origin as it has been considered by some workers.

Dr. Ramsey finds, with respect to the veins of the endometrium at the implantation site, that as pregnancy advances the number of venous channels draining the base of the placenta diminishes, until much the greater part of the venous drainage is into the marginal sinus.

This evidence from a whole series of monkey placentas, graded by age from relatively early to late in gestation, helps to explain the failure of certain workers (e.g. Spanner) on human placentas to find basal placental drainage in the relatively late specimens at their disposal; but on the whole the findings confirm the general theory of placental circulation put forward by Spanner (1934 to 1940) and show that his "overflow" type of filling and emptying of the intervillous space operates in the rhesus monkey as well as in humans, despite minor structural differences.

PHYSIOLOGY OF THE UTERUS

Uterine contraction pattern during labor. Last year's report (Year Book No. 47) included a description of the strain-gauge tokodynamometer invented by Dr. Reynolds for the primary purpose of recording the movements of the human uterus dur-

ing the advanced stages of pregnancy and especially during labor. The instrument, applied without harm and without great inconvenience to the abdomen of the patient, simultaneously records the activity of the muscular wall of the uterus at three different positions, the fundus (i.e. the upper part of the uterus, which is the bottom of the uterine bag), the middle, and the lower end near the outlet. Thus it provides information not only about the strength, duration, and rate of the contractions of the uterus, but also about the relative strength and rate at the three levels. Gradients of force from one point of the uterus to another, and the origin, spread, and dissipation of the contraction waves, are recorded on graphs which can then be conveniently subjected to intensive study and analysis, of the progress of labor, its normal or abnormal character, and the effects upon the uterus of drugs administered to the patient. The instrument has been in active use in the Johns Hopkins Hospital maternity clinic since it first became available, and has been widely copied for use elsewhere.

The results of research with the Reynolds tokodynamometer carried out in the Johns Hopkins clinic have now begun to appear in published form. Dr. Reynolds, with the collaboration of Dr. Louis M. Hellman and Dr. Paul Bruns, of Johns Hopkins Hospital, laid the foundation for subsequent clinical reports by describing in the *Obstetrical and Gynecological Survey* the patterns of uterine contractility observed in normal labors and in some of the common types of abnormality (premature and false labor, uterine inertia). Normally progressing labor, as indicated by progressive dilatation of the cervix, is characterized by a gradient of diminishing physiological activity from the fundus to the lower uterine segment. Deviation from

this pattern is associated with prolongation of labor or failure of dilatation of the cervix. The gradient of activity is associated with a high tension in the tissues of the uterine wall at the fundal end, exceeding that in the cervix by about 3 to 1. This favors stronger contractions in the fundus than in lower parts of the uterus and hence contributes to the orderly emptying action of the uterus at parturition. The effect of rupture of the membranes is such that the relative tension at the fundus increases with respect to that at the lower uterine segment. The delicate balance of forces which prevents the untimely emptying of the uterus is thus tipped suddenly, by spontaneous or artificial rupture of the membranes, in a direction favoring delivery of the uterine contents.

Work done by the uterine muscle in labor. The same authors have presented a method of estimating the work done by the different uterine segments during labor. Their article was appropriately published in a Festschrift article for Professor Dr. E. Röthlin, of Basel, an eminent investigator of the pharmacology of the uterus. Graphs recorded by the Reynolds tokodynamometer from a normal labor provided the data for analysis.

The work done by the uterine muscle during the contractions could be computed by planigraphic measurements of the area of the curve under the graph of each contraction. To avoid the impracticable task of analyzing all records with a planimeter, a formula based upon the integration of the intensity, duration, and frequency of the uterine contractions was established, whereby the work per hour could be calculated from the graphs. Such calculated values proved to be parallel to those computed from planimeter measurements, and when corrected by a constant factor could be used to study the work done by various segments and the effect

upon the work of drugs administered to the patient. The formula may therefore be applied with confidence in subsequent studies upon records made with the tokodynamometer.

Recording uterine contractions in animals. Dr. Reynolds and Dr. Irwin H. Kaiser (formerly Fellow in the Department of Embryology) have shown how a dynamometer employing the strain-gauge principle can be used in measuring the responses of uterine muscular tissue of laboratory animals. In an anesthetized rabbit, for example, the uterus is exposed by an abdominal incision and a blunt needle is inserted into its cavity. Pressure changes within the uterus are thus communicated through a rigid tube to the strain gauge. The resulting graphs can be analyzed for the force of the contractions and for the work done. With this apparatus Reynolds and Kaiser have been able to study the quantitative effects of oxytocic (uterus-stimulating) and antihistaminic drugs. The latter (Pyribenzamine and Benadryl) were found to be in general oxytocic, affecting both muscular tone and rhythmic contractility. The hormonal status (pregnancy, nonpregnancy) does not affect the responsiveness of the rabbit's uterus to Pyribenzamine as it does to the pituitary oxytocic substance.

Uterine circulation time. Many recent investigators have suspected that there is a relation between deficient blood circulation in the uterus and toxic conditions during pregnancy. Thus there is a need for measurement of the uterine blood flow. Dr. Edward C. Gillespie and Dr. Reynolds have developed a very ingenious method of making such measurements in experimental animals and have applied it to the rhesus monkey. The technique depends upon observing and measuring the rate at which a substance injected into the muscle of the uterus is cleared away from the site

of injection by the circulating blood in comparison with the clearance of a similar injection into the abdominal muscles. By use of a new high-speed jet injection ("Hypospray") it is possible to propel fluids under the skin almost without pain. The depth of penetration is controllable by the operator. Gillespie and Reynolds found that such injections of the radiopaque dyestuff Diodrast could be made twice weekly in pregnant monkeys without harm. In a typical series shown in their paper (106 days gestation) the clearance of 1 cc. of the dye from the monkey's uterus required 34 minutes, from the abdominal muscle 25 minutes.

Adaptation of uterine blood vessels and accommodation of the products of conception. As the fetus grows, the uterus in which it lies must enlarge with it. The process of uterine growth is not, however, one of mere stretching and enlargement until some extraneous agent causes the uterus to empty itself; it involves an elaborate series of adjustments of the uterus in form and function, resulting in exact adaptation to its contents. For some years Dr. Reynolds has been giving his attention to the various elements of this adaptive process. In volume 33 of the *Contributions to Embryology* he presents a detailed study of the part played by the blood vessels of the uterus in its accommodation to the products of conception. The data presented were obtained from observations and experiments on rabbits by a wide variety of technical methods involving chiefly injections with diffusible dyes and corrosion preparations. A summary of the results shows, first, that there are two distinct phases in the adjustment of the uterine vascular system to the shape and size of the conceptus. The first of these involves progressive stretching of the blood vessels about the spheroidal conceptus. A maximum degree of distention

is attained about the 22d day of pregnancy in the rabbit. At this time, the second phase of the vascular adjustments takes place after quick conversion of the conceptus to a cylindrical form. The period of rapid fetal growth which ensues involves only lengthening of the uterus. The effect of this upon the blood vessels in the uterus is to cause them, by virtue of their special arrangement, to be separated from one another in the latter part of gestation, without further increase in length. As a consequence, the hemodynamic work involved in moving blood through the uterine blood vessels is no greater when the fetus weighs 80 gm., near term, than at the time of conversion, when it weighs a fourth or less of that amount.

A special mechanism exists by which blood is shunted through the placenta at the time of uterine ischemia, prior to conversion of the conceptus from a spheroid to a cylinder. This shunting takes place by virtue of the existence of two more or less discrete vascular areas in the uterus arising from a common arterial supply. One area (placental) is along the mesometrial border of the uterus, the other (intramural) is over the lateral and ventral aspect of the uterus. The uterus, by virtue of the shape imposed upon it by the conceptus, is subjected to greatest tissue tension on its lateral aspect. That this tension offers resistance to the flow of blood is shown by resistance to passage of dyestuffs and other substances injected experimentally through vessels on the ventral surface of the uterus around spheroidal conceptuses.

Hydrostatic factors within the uterine tissues affect the flow of blood through the blood vessels within them. Although there is a pattern of hormonal changes within the maternal organism throughout pregnancy which affects at any given time the general level of tonus of the uterine muscle,

these changes are superimposed upon a morphological relationship by which the tension to which the tissues are subjected is a function of the factors of the internal pressure and the radius of curvature at any point. Hormonal factors exert themselves by changing the pressure within the uterus through their action on the myometrium, whereas the shape and size of the conceptus influence the tension within the uterus by affecting its radii of curvature.

The uterus in premature birth. The observations on the physiology of the uterus made by Dr. Reynolds and his co-workers during the past several years, all of which have been summarized in the Year Books, could not fail, of course, to yield results of interest to obstetricians. Dr. Reynolds has been in great demand as a lecturer before obstetrical societies. In one of his lectures, given at Denver in May 1948, he outlined the bearing of his findings upon the problem of premature birth, pointing out that the phenomenon of "conversion" or elongation of the uterus during the sixth month of pregnancy, and the associated changes in the circulation, constitute a critical period at which premature birth becomes a special danger. In such studies as he has been making, however, lies the best hope of finding ways and means to recognize impending premature birth and ultimately to ward it off.

ANATOMY AND PHYSIOLOGY OF THE OVARIAN ARTERIES

In the last two Year Books (Nos. 46, 47) reference was made to the observation by Dr. Reynolds that in the human ovary, as well as in the ovary of the rabbit (and presumably of other animals), the ovarian artery has a conspicuously spiral course as it runs along the hilum of the ovary. Evidence that this peculiar condition is dependent upon the presence of estrogen

secreted by the ovary, mentioned last year, has now been published by B. Delson and S. Lubin, of the Cumberland Hospital, New York City, in collaboration with Reynolds.

The same three authors, writing on the vascular patterns in the human ovary, note that the vascular system is more complex than in the rabbit. The branches of the main ovarian artery are helical, with gradually diminishing diameter. The functions of spiraling in these vessels are thought to be (1) adaptation of the vasculature to growth of the ovary and (2) provision of a mechanism for the reduction and regulation of blood pressure within the ovary. When ovarian function diminishes with age, the spiraling decreases. The occurrence of spiraling in the prenatal ovary is presumably stimulated by maternal estrogenic hormones, and its regression, which occurs during several months after parturition, is thought to be due to the removal of their influence.

The hypothesis that coiling of the ovarian artery affords a means of rapidly reducing blood pressure in the ovary as compared with that in the systemic arteries is subject to analysis by hydrostatic theory from measurements of the arteries. Dr. Reynolds points out in the Swiss journal *Acta anatomica* that there are several mechanisms which on physical grounds may be involved in such a reduction. One of these is the rapid decrease in diameter of the ovarian artery after it enters the ovary. Another is the effect which the coiling has in increasing the length of vessel to be traversed by the blood per unit distance along the hilum of the ovary. Reynolds then proceeds to show by hydrostatic theory that the coiling acts also to favor streamline or axial flow under conditions which would give rise to turbulent flow if the vessels were straight.

Angles of branching in the ovarian ar-

tery. In the ovary, more than in most other organs, there is much internal change of structure. The rapid growth and regression of the follicles and the corpora lutea, and the frequent occurrence of minor or major pathological structures (cysts), continually produce alterations in the pattern of the organ and of its constituent elements, particularly the blood vessels. In spite of this, the ovary seems to obey the general law that the blood flow is approximately equal in all parts of an organ. Older writers (Thoma, Hess) long ago laid down certain general principles which are involved in the equalization of blood flow in organs, basing them upon the ratio of the diameters of arterial branches to those of their main stems, and upon the angles formed between the stem and its branches. Dr. Reynolds, in the same article to which reference was made in the preceding paragraph, has sought to find a formula for the angulation of branches of the ovarian arteries. Using one of his corrosion preparations of the rabbit's ovary, in which the channels of the blood vessels are preserved as casts in solid plastic, he measured the angles of branching. The result confirmed a general principle set forth by Sir D'Arcy Thompson in his famous book *On growth and form*, which states that the normal pattern of the blood vessels is such that the circulation can be maintained with minimum effort and a minimum of wall surface. The essential factors in branching arteries which govern this relationship are (1) the diameter of the branch relative to that of the stem, and (2) the angle of branching. It follows from these facts that there must be a relation, expressible by a mathematical formula, between the diameters of arteries and the angles of branching. Dr. Reynolds finds that the following formula fits the specimen he has intensively studied: K (coefficient of arterial branching) =

diameter of branch divided by diameter of stem \times cosine of angle of branching.

The article is illustrated with a beautiful three-color half-tone stereoscopic picture, removable for use in the stereoscope, from a photograph by Chester F. Reather.

PHYSIOLOGY OF MENSTRUATION

Prostigmine. In 1940 Soskin, Wachtel, and Hechter reported that the cholinergic drug prostigmine, when administered hypodermically to women suffering from delayed menstruation, will bring about menstruation within three days. Since a woman who is not menstruating (because of pregnancy) does not respond in this way, Soskin and his colleagues suggested that the finding could be made the basis of a test for pregnancy. They explained the induction of bleeding by prostigmine by certain elaborate pharmacological assumptions involving the mechanism of menstruation and its failure in amenorrhea. The finding has been widely advertised in pharmaceutical literature, and there have been numerous clinical papers supporting the observation, though few of them are scientifically critical. For this reason Dr. Corner tried prostigmine in monkeys, soon after the Soskin report appeared, administering it during the summer amenorrhea that is characteristic of rhesus monkeys in captivity in our climate. Menstruation was not induced. These unpublished experiments were greatly extended by Dr. Irwin H. Kaiser during his recent incumbency of a fellowship in the Department of Embryology. He found that prostigmine does not induce menstrual bleeding in spontaneously amenorrheic animals, or in castrated animals during estrogen treatment; nor does it alter hormone-withdrawal bleeding following courses of estrogen, estrogen with progesterone, or a sequence of estrogen-

progesterone-estrogen simulating the normal cycle.

These conditions under which prostigmine failed to induce menstruation in monkeys are not exactly similar to the kinds of amenorrhea in human patients in which it is claimed to be effective. They do not therefore of themselves invalidate the results on humans, but they do call for greater caution than has been used by some of the clinical writers.

Estrogen and the endometrial coiled arterioles. Many students of menstruation during the past twenty-five years have been tempted to assume that the coiling of the arteries of the endometrium is in some way causally related to the bleeding of menstruation, because (speaking approximately) the phenomenon of menstruation and the phenomenon of coiling of the endometrial arteries both occur only in the higher primates (man, apes, and Old World monkeys). In Year Book No. 47 reference was made to Dr. Kaiser's observation that a process resembling menstruation occurs in certain New World monkeys which do not have coiled endometrial arteries.

In a subsequent publication he now reports having produced experimentally in rhesus monkeys, which normally have coiled endometrial arteries, a condition in which they lack such arteries, and yet undergo bleeding of a type usually thought identical with menstruation. This was done by giving massive doses of estrogenic hormone to castrated rhesus monkeys. Discontinuance of the injections was followed, as expected, by menstruation-like bleeding. Post-mortem examination of the uterus under similar experimental conditions (i.e. after 4 weeks of massive dosage) revealed excellent proliferative development of the endometrium but virtual absence of coiled arteries.

In the *American Journal of Obstetrics*

and *Gynecology* for December 1948 Dr. Kaiser reviewed the newer concepts of menstruation. It has been known for some years that the menstrual blood flow results from a sudden drop in the concentration of ovarian hormone (estrogen) in the blood at the end of the menstrual cycle, but just why the hormone deprivation causes the blood vessels in one particular organ, the uterus, to break down with ensuing hemorrhage has been a matter of much conjecture and of largely unsuccessful experiment. A number of recent workers have set up new hypotheses involving details of the uterine vessels, i.e. the coiled arteries mentioned above; supposedly numerous arteriovenous anastomoses; an apparently inadequate lymphatic drainage. Dr. Kaiser's article reviews these hypotheses in the light of his own observations of the nonessentiality of the coiled arteries to the menstrual process. The problem remains one of the outstanding mysteries of human biology.

ENZYMES I EMBRYONIC TISSUES

Dr. Josefa B. Flexner and Dr. Louis B. Flexner, working in part under an American Cancer Society grant recommended by the Committee on Growth of the National Research Council, have added another contribution to their series on biochemical and physiological differentiation during morphogenesis. They are currently interested in studying the turnover of phosphorus in the metabolic processes of growing tissues, in relation to the rate of growth and the degree of differentiation of the tissues in form and function. The present article deals with the presence and activity, in the fetal brain and liver of the guinea pig, of two enzymes that are concerned with phosphorus metabolism, namely adenylypyrophosphatase ("apyrase") and acid phosphatase.

The first of these (apyrase) is a substance or group of substances found in animal cells which has the property of releasing energy for use in bodily work from energy-rich phosphorus compounds such as phosphocreatine and adenosine triphosphate. A similar enzyme in muscle, adenosine triphosphatase (myosin), has been isolated and identified chemically. In other tissues the chemical nature of the enzyme is not so clearly defined, hence the use of a different name, adenylpyrophosphatase, or apyrase for short.

The authors find that a critical time with regard to apyrase in the brain cortex of the fetal guinea pig is reached at the 42d day of gestation. At this time the activity of the enzyme suddenly begins to rise from a relatively low level toward the high concentration which is found at the time of birth and in young animals. Much the same is true of the fetal liver. The activity in both tissues is still higher in older animals.

Acid phosphatase, which splits the phosphates in acid environments, is widely distributed in the body. It presents a challenge to the student of animal metabolism by reason of our ignorance of its function. In the fetal liver this enzyme was found by Flexner and Flexner to follow a curve similar to that of apyrase. In the brain cortex, however, it behaves differently, for here it is at a constant level of activity about twice as high as that found in the adult.

PERMEABILITY OF THE HUMAN PLACENTA

Frequent reference has been made in these reports to the researches led by Dr. Louis B. Flexner on the function of the placenta, and to the joint efforts to apply his methods to the human placenta in which Dr. Louis M. Hellman and Dr. G. J. Vosburgh, of the Department of

Obstetrics of the Johns Hopkins Hospital and Medical School, have been associated. These three, together with Dr. W. S. Wilde and Mr. N. K. Proctor, have now published another contribution in which they report on the permeability of the human placenta and the supply of water to the human fetus, as studied by the use of deuterium oxide (heavy water) as the tracer substance. Observations were made upon 7 patients whose pregnancies were being terminated by abdominal operation at various stages of gestation, because of serious conditions involving danger to the mother. Measured small amounts of deuterium oxide made isotonic with sodium chloride were injected into the mother's veins about 10 minutes before the obstetrician delivered the fetus and clamped the umbilical cord. The amount of the heavy water which passed from the mother's blood through the placenta to the fetus was ascertained in the case of the older viable fetuses from blood samples, and in the case of the younger, nonviable fetuses by direct extraction of the fetal tissues. The result, as expressed in a graph showing the rate of transfer of the water, agrees with the experience of Flexner and his colleagues with regard to the transfer of sodium through the human placenta, and of several other substances in animals. In view of the laborious nature of the experiments the authors feel that they are justified in presenting conclusions from only 7 patients. There was a fivefold rise in permeability of the placenta to water from the 14th week of pregnancy (the earliest case in the series) to a peak at the 35th week, and thereafter a sharp decline to term. At the peak, the very large quantity of 3.6 liters of water per hour crossed the placenta to the fetus. The placental transfer coefficient for water is five times as great

as that for sodium at corresponding periods of gestation. The human fetus receives across the placenta at the 14th week of gestation 700 times and at the 31st week 3800 times as much water as is incorporated in the growing tissues.

CAPILLARY PERMEABILITY

The use of substances such as heavy water and radioactive salts, which do not significantly differ from the ordinary water and salts of the body in their physiological activities, but are easily identified as they travel through the body by their weight or radioactivity respectively, is not of course limited to the study of special problems, such as the rate of placental transfer, in which Dr. Flexner first used such substances. He and his colleagues have in fact for some years been applying the tracer method to the more general problem of the permeability of the blood capillaries. As participants in the Cold Spring Harbor Symposium on Quantitative Biology in the summer of 1948, Dr. Flexner, Dr. Dean B. Cowie of the Department of Terrestrial Magnetism, and Dr. Gilbert J. Vosburgh of the Department of Obstetrics, Johns Hopkins University and Hospital, presented a summary of the joint studies in which they and others (A. Gellhorn, M. Merrell, R. M. Rankin, R. O. Scholz, W. S. Wilde) have taken part.

Among the four major problems to which they have contributed, the first is that of the rate of exchange of water, of sodium, of chloride, and of iron (in the physiologically important form of ferric beta₁-globulinate). These substances, marked by their weight (heavy water) or by being made radioactive, are injected into a blood vessel and the rate of their escape, as measured by the amount still in the blood stream after various time intervals, is determined. The results show in the

first place that the substances named pass through the walls of the capillary blood vessels into the surrounding tissues at different rates for different substances. The average capillary wall of the guinea pig is 23 times as permeable to water as to sodium and to chloride, and at least 100 times as permeable to water as to ferric beta₁-globulinate.

In man, 78 per cent of the blood-plasma sodium and 105 per cent of the plasma water is exchanged per minute with extravascular sodium and water. An amount of water equal to a man's entire weight passes out of his blood capillaries, and is replaced by an approximately equal amount, every 20 minutes. The capillary part of human blood circulation, seen in the light of these facts, is a system of fine tubules with permeable walls through which floods of water bearing salts and other metabolic substances are pouring at every moment throughout life.

A second problem which is largely solvable by the tracer method concerns a much debated hypothesis that whereas water and dissolved gases pass through the whole of the thin protoplasmic wall of the capillary, i.e. through the endothelial cells as well as the intercellular cement, the only important avenue for escape of the electrolytes is the cement substance, much as if one should say that water running through hollow tiles could leak through both the tiles and the joints between them, but salt only through the joints. Flexner, Cowie, and Vosburgh make a calculation based on an estimate of the area of the capillary wall to which 1 ml. of plasma is exposed, on the diffusion constant of a salt (KCl), and on the concentration gradient of the salt in the blood plasma. From these data the theoretical amount of potassium chloride which can diffuse across the interface per day can be worked out. The amount of radioactive chloride which actu-

ally moves across the capillary wall in a unit of time was previously measured (Cowie, Flexner, and Wilde, 1941). This proves to be about what would be predicted if the electrolyte were diffusing through the whole available wall, rather than through the far smaller area of the intercellular cement. The same deduction may be made for water and for sodium.

A third problem is to determine whether, as has been thought by some workers, the dissolved substances of the plasma pass the capillary wall "in bulk"; that is, do all go across in the same concentration that exists in the plasma, or do they cross the wall in different proportions? Results show that the latter supposition is correct. The fluid passing through the capillary wall is found to contain a far smaller proportion of ferric globulinate than of chloride to the amount of these respective substances in the plasma. The iron-protein compound is thus largely held back within the capillary while the water and salts freely interchange with the same substances in the tissues.

Finally, the method permits deeper insight into the physical processes involved in passage of the capillary wall by these substances, indicating that diffusion rather than filtration is the essential process.

Transcapillary exchange of iron; assay of iron. A separate paper by the same three authors, presenting the observations on which the above statements about the transcapillary exchange of iron were based, will be found listed in the bibliography appended to this report. In order to make accurate determinations of radioactive iron in biological material, an improved method of assay had to be developed. This also is cited in the bibliography.

THE AMNIOTIC FLUID

The fluid that exists about mammalian embryos and fetuses within the amniotic

membrane, serving to float the embryo and protect it from physical shock, presents interesting problems concerning its formation and the rate of exchange of its water with the water of the mother's blood, from which it is ultimately derived. The amniotic fluid has generally been considered to be rather stagnant. Some writers have thought that it consists mainly of urine discharged by the fetus. That dyestuffs may be made to pass into it from the mother's blood has been known. Flexner and Gellhorn applied the isotope technique to the problem in 1942, using guinea pigs, and found that the water of the fluid is replaced at the surprisingly rapid rate of about once an hour, whereas the rate of replacement of the sodium is about 50 times slower. The transfer of water and sodium to the human amniotic fluids has now been measured, using deuterium oxide (heavy water) and radioactive sodium (Na^{24}) as tracer substances. The observations required a team of specialists, namely two obstetricians, G. J. Vosburgh and L. M. Hellman, of the Johns Hopkins Hospital, Department of Obstetrics; a physicist, D. B. Cowie, of the Carnegie Institution's Department of Terrestrial Magnetism; and three physiologists, L. B. Flexner, W. S. Wilde, and N. K. Proctor, of the Department of Embryology. The tracer substances were injected intravenously into pregnant women who were undergoing operative procedures involving surgical exposure of the uterus. At measured intervals after the injection, samples of the amniotic fluid were drawn through the wall of the intact uterus with needle and syringe and were submitted to measurement of the deuterium oxide and the tagged sodium. Details of the method and calculations are given in the paper. It was found that the water of the human amniotic fluid is completely replaced on the average once every 2.9 hours. The sodium

is transferred about 5 times more slowly than the water. At term a fetus weighing 3.4 kg. is surrounded by approximately 1000 cc. of amniotic fluid which is exchanging water at the rate of 350 cc. per hour. This is by no means a condition of stagnation; indeed, it is astonishingly rapid. The fetal urine alone cannot account for so much water, which therefore is probably furnished directly through the amniotic membrane.

SEX RATIO OF ABORTIONS

Wherever human birth records are kept, it appears that among newborn infants boys are slightly more numerous than girls. In the United States the sex ratio for live births is 105.6 boys to 100 girls; for stillbirths, 124.1 to 100, and for the two groups combined, 106.0 to 100. The sex ratio at the time of conception in man ("primary sex ratio") is not accessible to direct observation. Dr. E. Carlton MacDowell, of the Department of Genetics, arrived some years ago at the sex ratio of mice at conception by an ingenious method requiring surgical exploration of the mother's ovaries, and found it approximately 1:1. If the primary sex ratio in man were also 1:1, the figure of 105.6 to 100 at birth would mean that a slightly greater number of female embryos than of male succumb during gestation. On the contrary, however, widely accepted reports made during the past hundred years have asserted that many more male embryos and fetuses than female succumb during gestation. The sex ratio of aborted fetuses has generally been reported still higher in the earlier months of gestation than in the later months and at birth. Four of the largest reported series of observations when combined give a sex ratio of 224 (males to 100 females) in the 4th month, 143 in the 5th, 121 in the 6th, and 114 in the 7th

month of gestation. The primary sex ratio has therefore been estimated by various writers, by extrapolation from such figures, at from 125 up to 170. No sound reasons for any such excess of male conceptions, or for such high mortality of male infants in utero, have been put forward.

Dr. Christopher Tietze, a physician and statistician associated with the School of Hygiene, Johns Hopkins University, has reinvestigated the sex ratio of abortions by analyzing the records of the Department of Embryology, which provide the only large series of sex determinations of human fetuses made entirely by trained observers under uniform conditions. A similar analysis published in 1921 by Dr. A. H. Schultz, then a member of the Department, gave an unweighted mean sex ratio of 109 for the 3d to the 7th month of pregnancy inclusive. The Carnegie Collection, having grown greatly, now affords more material for statistical study. Dr. Tietze abstracted from the main catalogue of the Collection records of 5667 fetuses from the 4th to the 7th month. Their sex had been determined by members of the research staff or by trained technicians. This series was supplemented by 120 specimens of the 3d month, the sex of which was determined by microscopic examination of the gonads, largely by the late Dr. George L. Streeter. The help given Dr. Tietze by Dr. Streeter was the last of the latter's many co-operative services to fellow scientists. These 120 specimens of the 3d month had a sex ratio of 93.5 males to 100 females. The fetuses of the 4th, 5th, 6th, and 7th months had ratios of 107.7, 115.6, 109.7, and 100.6 respectively. The mean ratio of the 5787 cases was 107.9. Dr. Tietze's analysis therefore reveals no evidence for a primary sex ratio materially different from that found at the end of pregnancy among the combined live and stillbirths. He tentatively ascribes the

widely different reports based on other material to errors in determining sex made by medical men without special training in embryology, or by midwives. Such errors are the more likely to occur, the earlier the fetuses and embryos studied.

NUMBER OF YOUNG AT BIRTH; NUMBER OF NIPPLES

Dr. Adolph Schultz, of the Department of Anatomy, Johns Hopkins Medical School, a former member of the Department of Embryology, from time to time makes use of the Carnegie monkey colony records and specimens in his biometric studies of primates, as for example in an interesting recent report on the number of young at a birth and the number of nipples in primates. The Carnegie colony of rhesus monkeys has had one twin birth in 188 pregnancies. Schultz has assembled records on twinning in other monkeys, which suggest that twinning occurs in most catarrhine monkeys and in apes with a frequency not far different from that in the human species. A frequently cited theory that twinning in man is a newly acquired character, from the evolutionary standpoint, is not supported by this study.

In the entire suborder of simian primates, 2 pectoral nipples represent the normal condition. Supernumerary nipples, however, have been found in 40 monkeys and apes from 10 species representing all the major groups except the Semnopithecinae. They are not uncommon in human beings. Dr. Harold Speert's Carnegie cases in the rhesus monkey, referred to in Year Book No. 41, and those now reported by Schultz, give a rate of frequency of 1.4 and 1.1 per cent respectively, which is close to that in man. The general percentage frequency in monkeys, apes, and man is very similar and lies not far above 1 per cent. The primitive character of 2 or 3 pairs of

nipples is more common in the lower primates (prosimians), but the number of nipples varies from species to species and often even within the species.

PALATINE RIDGES OF PRIMATES

In the majority of mammals the lining of the hard palate bears ridges, more or less transversely directed, which differ widely in number and relative size. In the human species the palatine ridges are reduced in number and are usually limited to the area in front of the first molar teeth, but any reader of this report will find, by passing his thumb over the front part of the roof of his mouth, that he possesses 2 to 8 ridges, the average in man being 4.2. Many conclusions have been drawn from the palatine ridges about the evolutionary relationships of mammals, including the relation of man to the other primates. Two great comparative anatomists, Retzius and Gegenbaur, have stated that the human ridges are more numerous in the fetus than in the adult, thus implying that the reduction in number seen in humans occurs ontogenetically, i.e. in the individual, as well as phylogenetically. Volume 33 of the Contributions to Embryology contains a thorough quantitative study by Dr. Adolph H. Schultz of the comparative anatomy of the palatine ridges in primates generally and of their ontogenesis in man. Thirty-two human fetal palates studied by Dr. Schultz were obtained from the collection of the Department of Embryology.

Dr. Schultz concludes that the primitive common ancestor of the primates had numerous large, regular palatine ridges, reaching back to the last molar teeth. This is the usual condition in a great variety of lower mammals. The ridges have become significantly changed in many

groups of primates, and the alterations reveal phylogenetic trends. Dr. Schultz's article must be read to appreciate the variability. He finds that the ridges can be recognized in a human embryo of 28 mm., making their appearance prior to the normal embryonic fusion of the two lateral palatine processes. Thus failure of the latter to fuse, resulting in cleft palate, does not prevent the formation of ridges. The average number of ridges is the same in

fetuses as in adults; this means that there is no reduction in their number during growth of a human individual. The palatine ridges of single-ovum twins show only a limited degree of resemblance, and it appears therefore that the details of the ridge pattern are not closely determined by heredity, although the general degree of regularity and the tendency toward unification and discontinuity of the ridges must have a genetic basis.

DIFFUSION AND POPULARIZATION OF RESULTS

In September and October 1948, Dr. Corner presented lectures, based in large part on work done by himself and other members of the Department of Embryology, before the Linn County Medical Society, Cedar Rapids, Iowa; the Hollywood (California) Academy of Medicine, the San Diego Academy of Medicine, the Southwestern Pediatric Society (Los Angeles), the Los Angeles Obstetrical and Gynecological Society, and the New Mexico Clinical Society. Dr. Burns addressed the Regional Post-Graduate Seminar of the American Urological Association at Buffalo in January 1949, on "The hormones and the differentiation of sex in the mammalian embryo," and also spoke at the University of Rochester on the same subject. Dr. Reynolds gave lectures and talks on problems of uterine physiology

during the year at the University of Maryland, the New York Obstetrical Society, and the Obstetrical Society of Boston. Drs. Corner, Burns, Flexner, Reynolds, and Tyler each gave one or more lectures by invitation before classes in anatomy, physiology, and obstetrics of the Johns Hopkins University, School of Medicine.

Mr. Chester F. Reather, departmental photographer, was given the first award for gross-specimen photography of the Biological Photographic Association for a picture shown at the association's 1948 annual convention at the University of Pennsylvania. The photograph, a superb picture of a human embryo in its membranes (Carnegie Collection, no. 8537A), has been reproduced by half-tone in *Medical Radiography and Photography* (see bibliography below).

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DEPARTMENT OF GENETICS

Cold Spring Harbor, Long Island, New York

M. DEMEREC, *Director*

Members of the Department continued their studies of the nature of the hereditary materials, genes and chromosomes, using a variety of approaches and several different organisms in their experiments. McClintock's cytogenetic studies on maize have given further evidence of the biological complexity of a gene locus, and are revealing one of the possible mechanisms through which genetic instability may be attained and genic differentiation increased. Corroborating evidence of the complexity of a gene locus has been obtained in the work of Demerec and his collaborators with a strain of the bacterium *Escherichia coli*. The biochemical work carried on by Kaufmann, McDonald, and their group with chromosomes of *Drosophila* and several plants is beginning to throw light on the chemical organization of these structures. Studies by Caspari and Dalton, dealing with pigment development in the meal moth and the axolotl, have analyzed the mechanism of the gene action controlling this process. The work of MacDowell and his collaborators with mice has gone farther in demonstrating the importance of factors such as virus infection and mother's and nurse's age in the development of leukemia. Efforts to discover chemicals capable of inducing mutations in *E. coli* have been continued by Demerec, Bertani, and Flint, using a newly developed method involving reversions in this material from the streptomycin-dependent state. Witkin, also working with *E. coli*, has found that sodium nucleate has a striking effect on the time of expression of certain mutants. Doermann investigated a strain of bacterial virus that shows

a high rate of mutations; and Delaporte made cytological observations of the strains of bacteria being used in our various studies. Dobzhansky spent fifteen months in Brazil, studying the dynamics of *Drosophila* populations in tropical and subtropical environments.

The study of mutable loci in maize was continued by McClintock in an effort to determine the mode of origin of mutable loci from normal loci and the nature of events occurring at such a locus to bring about detectable changes in its phenotypic expression. Investigations this year were confined to the *Ac* (activator) locus and to the group of *Ac*-controlled mutable loci, which require the presence of this second locus for expression of their mutability. It was concluded that the origin of all mutable loci in this class is associated with the transposition of a single locus, *Ds*, from one position in the chromosomal complement to another. The insertion of *Ds* at or near a normal locus may inhibit the action of the normal locus, and thus change its phenotypic expression. Continued changes in the phenotypic expression of the affected locus are related to subsequent events that partially or completely remove this inhibitory action by removal of the *Ds* locus, or that change the constitution or position of *Ds* with reference to the affected locus. The events occurring at *Ds* to bring about such changes result from compound chromatid breaks at this locus. The change in expression of the affected locus depends on the type of fusion of broken ends that follows such breakage events. In several cases, the insertion of *Ds* into or adjacent to a normal locus has

made it possible to analyze more fully the composition and action of the normal locus. This analysis has revealed that one of the normal loci studied is compound, in that it is responsible for at least two reactions associated with the appearance of a single end product. *Ac* itself is a mutable locus. It also undergoes transpositions from one position in the chromosomal complement to another. The mechanism responsible for the transposition of *Ac* and the production of various alleles of this locus is probably the same as or similar to that associated with transpositions and changes of the *Ds* locus.

The patterns of mutation in *E. coli* to streptomycin resistance and dependence, and of reversion from dependence to non-dependence, were studied by Demerec through analysis of the various properties of about 280 separate mutants. Most of these mutants were found to differ from one another, indicating that a reversion from dependence to nondependence probably comes about not through a reversal of the chemical reaction that originally produced the dependent mutant, but through some other change in the gene complex. Tests made with the K-12 strain of *coli* by Lederberg's method indicate that either a single locus or adjacent loci are responsible for these various mutants. As a rule, each mutant shows the effect in more than one characteristic.

Bertani, Demerec, and Flint investigated mutagenic activity in several chemicals by determining their effect on the frequency of reversions in *coli* from streptomycin dependence to nondependence. Induction of mutations was observed with the following chemicals: formaldehyde, acriflavine, phenol, caffeine, ethyl carbamate, ammonia, and ferrous chloride. In comparison with radiations and mustard compounds, all these except ferrous chloride

have a low order of mutagenicity. Ferrous chloride in experiments with *coli* is as strong a mutagen as X-rays, ultraviolet rays, or nitrogen mustard.

Demerec also studied in *coli* the patterns of resistance to aureomycin, chloromycetin, and neomycin, and found that there is a stepwise increase in resistance to each of these three antibiotics.

The effect of sodium nucleate on the phenotypic expression of delayed mutations to phage resistance in *E. coli* was investigated by Witkin and Flint. Exogenous nucleic acid can apparently take the place of division in causing delayed mutations to become phenotypically effective.

A new technique for the study of the mutagenic action of certain chemicals was developed by Witkin. The method involves the treatment of bacteria with an inhibitory or toxic compound, the action of which can be specifically reversed by the addition of another compound. This inhibition-reversal system provides a sensitive method for the detection of mutations induced by the inhibitory agent.

Doermann continued investigation of the intracellular growth of bacteriophage along several lines, with emphasis on the genetic approach to this problem. He showed that genetic recombinants are present among the earliest-formed phage particles in bacteria infected with two genetically different phages. This result, taken in conjunction with other genetic information, shows conclusively that phage multiplication is not accomplished by simple fission of virus particles, but that some other mechanism is responsible. The previously described cyanide-lysis method for studying the intracellular bacteriophage population has been modified in such a way that the intracellular phage of individual bacterial cells can be analyzed qualitatively and quantitatively. With this modified method a

study was made to see whether reciprocal exchange is the mechanism of producing genetic recombination among bacteriophages. Although reciprocal exchange was not ruled out completely, its occurrence was shown to be highly improbable, at least during the later stages of virus development.

Doermann and Dissosway made preliminary studies on a genetically unstable series of bacteriophages. The hereditary changes observed appear to be related to alterations in the requirements of the various types for adsorption cofactors. The fact that four new types invariably appear in one plaque arising from a single phage particle implies a fairly high rate of mutation. The quantitative expression of this rate is very much exaggerated, however, by selective factors acting during the growth of the plaque.

Cytochemical studies were continued by Kaufmann, using purified enzymes. A technique of dissecting the chromosome by successive treatments with nucleases and proteases has indicated that this structure represents an integrated fabric, in which no single protein or nucleic acid may be regarded as the primary structural component. In the course of this analysis it was found that the cellular dissolution usually attributed to the specific action of trypsin is due to the removal by water of degradation products of the action of trypsin in combination with electrolytes.

Kaufmann, in extending his studies of the action of near infrared radiation on living cells, did not detect any modification by this portion of the spectrum in the frequency of mutations induced by X-rays in the bacterium *E. coli*.

McDonald found that when dilute solutions of crystalline trypsin in 0.005 N hydrochloric acid are exposed to X-radiation, the ability of the enzyme to hydrolyze

denatured hemoglobin is partially destroyed. For any one enzyme concentration, the residual activity is an exponential function of the dose. In the range of concentrations thus far studied (3×10^{-8} to 9×10^{-8} molar) the ionic yields are not constant, but increase with increasing concentrations of trypsin.

Further studies by MacDowell with transplanted leukemia of line I, freed from a long-unrecognized virus infection, prove that the virus and not the increasing potency of the leukemic cells has been responsible for the death of hosts of a certain foreign strain that had previously been naturally resistant. Hosts of this strain are now as resistant as ever to these virus-free leukemic cells. The virus is lethal to the foreign strain but nonlethal to the strain of hosts that carry the leukemic cells. The same interpretation holds for the breakdown of a 1:1 ratio of susceptible backcross hosts. With virus-free leukemic cells of this line, this ratio has been re-established. On the other hand, the removal of a virus from another line of leukemic cells (line L) has demonstrated that intrinsic changes within the leukemic cells, and not the infecting virus, were responsible in this case for the previously observed increased susceptibility of a strain of foreign hosts.

MacDowell observed also that the age of the nurse has as certain an influence after birth, upon the incidence of spontaneous leukemia and upon the length of life, as the age of the mother has before birth, according to preliminary but unquestionable results of an experiment testing these variables. In F_1 hybrids from leukemic-strain fathers, leukemia is less frequent and life longer when the nonleukemic mothers and nurses are old. But with young mothers, old nurses transmit as much resistance to the appearance of spontaneous

leukemia and as great lengthening of life of both leukemics and nonleukemics as do old mothers with young nurses.

The mechanism of gene action in controlling development of pigment-pattern differences between the white and black strains of the Mexican axolotl was investigated by Dalton, using methods of tissue culture and embryonic transplantation. Study of chromatophores of both strains in vitro showed that the genes *D* and *d* do not affect the chromatophores themselves in such a way that intrinsic differences in capacity for proliferation, migration, or pigment synthesis are demonstrable in tissue cultures. Embryonic transplantation experiments indicate that the genetic differences in pigmentation of the two strains are mediated through differences in tissue environment and not in the chromatophores themselves, the white pattern resulting from an inhibitory effect concerned with the migration of pro-pigment cells. The results fail to support the view, suggested in the literature, that the mechanism of gene action in this case involves a diffusible substance necessary for melanin synthesis, contributed to pro-pigment cells by epidermis of the black strain but lacking in the white strain. Furthermore, the assumption, on which this was based, that pro-pigment cells in the white axolotl migrate as extensively as in the black, but do not produce pigment, is rendered questionable by results of Dalton's investigation. Inhibition of chromatophore migration by surrounding tissues of a particular genotype has not previously been described as a mechanism of pigment-pattern formation in amphibians. Demonstration of such inhibition in the white axolotl raises the question whether the pigmentation effects observed in other species combinations after reciprocal transplantations of epidermis may not in part depend on simi-

lar relations between epidermis and pigment cells.

The action of the genes *a* (red eyes) in *Ephestia* and *T* (Brachyury, short tail) in the mouse was investigated by Caspari, using serological methods. In *Ephestia*, serological differences between *aa* and *a'a'* genotypes could be established by titration and absorption experiments. An antigen differentiating the two strains was demonstrated in the euglobulin fraction. In the mouse, antigenic differences between *T/+* and *+/+* organs were found both by the precipitation method and by the complement-fixation method. With the latter method, the gene *Ki*, which is closely linked and phenotypically similar to *T*, turned out to be antigenically allied to but not identical with *T*.

Caspari, breeding normal animals obtained from crosses involving *Fu* (Fused), confirmed the hypothesis that *Fu/+* mothers adversely affect the penetrance of the gene *Fu*. In the offspring of normal animals from crosses of female normal by male Fused, there were occasional phenotypically Fused animals which bred as normals.

An enzyme system catalyzing the oxidation of tryptophane to kynurenin was studied by Caspari in homogenates from mouse liver. The enzyme was partly purified by fractionated precipitation with ammonium sulfate. The properties of the enzyme system and of the reactions catalyzed by it were investigated.

Delaporte studied the cytology of bacteria exposed to various influences such as changes in culture medium, irradiation with ultraviolet, infection by bacteriophage, culture on streptomycin, and inactivation by ultraviolet rays and subsequent recovery by light treatment. She found that all these conditions produce striking effects in the nuclear element of bacterial cells.

A project for study of population genetics of tropical *Drosophila* flies was developed by Dobzhansky, of Columbia University, Research Associate of the Institution, in co-operation with a group of investigators working, during the year 1948-1949, at the University of São Paulo and at the Instituto Agronomico do Norte, Belem do Pará, in Brazil. Samples of wild populations of *Drosophila* were collected in twenty localities, chosen to represent the various bioclimatic regions of Brazil. The collecting work required extensive travel, the distance covered within Brazil by airplane alone amounting to about 28,000 kilometers. More than 100,000 flies were collected and classified. Two species, *D. willistoni* and *D. prosaltans*, were subjected to cytogenetical analysis, the results of which will be reported later. For the time being, it can be stated that a great amount of genetic variability, both in mutant genes and in chromosomal aberrations, has been discovered in the natural populations of the two species, and furthermore that the quantity of genetic variants present in a population shows a significant relation to the environment in which the population lives.

For the past two years Dr. Ernest W. Caspari has been with the Department as a research associate, while on leave of absence from Wesleyan University, Middletown, Connecticut. He is returning to his former position in September. While here, Caspari carried out extensive research on the action of genes, investigating the chemistry of gene-controlled development of pigment in *Ephesia*, and studying the behavior of several genes in the mouse. He took part in many of the general activities of the Department, serving as chairman of the Seminar Committee and of the Library Committee. His profound knowledge of the literature made him a welcome

participant in discussions and a helpful adviser.

The fellowship program of the Institution has brought to the Department several young members who have been a great asset to the research program. Dr. A. H. Doermann was here for two years, working on reproduction and mutation in bacterial viruses. He left in the summer of 1949 to take a research position at the Oak Ridge National Laboratory of the Atomic Energy Commission. Dr. H. C. Dalton is remaining for another year to continue his research on pigment development in the Mexican axolotl. Dr. Berthe Delaporte, of the Centre National de la Recherche Scientifique in Paris, stayed at the Department for fifteen months, working on various cytological problems with bacteria. Dr. G. Bertani is now studying mutations in bacteria occurring spontaneously and induced by various chemicals.

The research program has been expanded through a grant received from the U. S. Public Health Service in support of Kaufmann's work, and through a grant of the American Cancer Society, recommended by the Committee on Growth of the National Research Council, supporting work of Demerec. Collaboration with the Biological Laboratory adds four research members to the group. Dr. V. Bryson, biologist at the Laboratory, is studying the biological aspects of the origin of bacterial resistance to various chemicals. Associated with him is Dr. B. Prytz, chemist, who is investigating the chemical aspects of the same problem. Dr. A. Kelner, bacteriologist, who left this summer, was successful last year in discovering the photoreactivation process, whereby microorganisms inactivated by ultraviolet irradiation partially recover after subsequent exposure to visible light. Dr. Bruce Wallace, geneticist, is studying the effect of continuous ex-

posure to radium on the genetic constitution of *Drosophila* populations.

The Cold Spring Harbor Symposium on Quantitative Biology, organized by the Biological Laboratory, brought more than 180 scientists to the Laboratory this June for a ten-day conference on the subject "Amino acids and proteins." Among the speakers at the conference were Kaufmann and McDonald, of the Department's staff. Seven of the speakers came from Europe,

and there were several other participants from foreign countries. During the rest of the summer, more than fifty scientists and their assistants from various institutions stayed at the Laboratory.

During the year the *Drosophila* stock center sent out 318 cultures to research workers, 53 of them to countries in Europe, Asia, and South America. The number of cultures sent to teaching laboratories in high schools and colleges was 666.

MUTABLE LOCI IN MAIZE

BARBARA McCLINTOCK

During the past year the study of mutable loci in maize has been continued, in an effort to determine the mode of origin of mutable loci from normal loci and to ascertain the events occurring at a mutable locus that result in detectable changes in phenotypic expression. Progress has been made with respect to both these objectives.

As stated in previous reports, two main classes of mutable loci have appeared and are continuing to appear in the maize cultures. One class includes a number of mutable loci that undergo changes in action only when a second locus, the activator (*Ac*), is likewise present. Mutable loci of the second class do not require such an activator locus. During the past year, study has been continued only on the *Ac*-controlled mutable loci. The decision to confine efforts to these mutable loci was made because all of them respond to the same *Ac* locus, regardless of the diversities of phenotypic expression they represent. On the basis of this common response to the presence of *Ac*, it could be suspected that the events leading to a change in phenotypic expression are of the same nature in all the *Ac*-controlled mutable loci. What are these events? Also, why do normal,

"wild-type" loci suddenly become unstable in these cultures?

Previous reports have discussed in detail the *Ac*-controlled mutable *Ds* (dissociation) locus. It was shown that *Ac* may induce chromatid breaks at the *Ds* locus that are followed by fusions of broken ends, and that these fusions may result in the formation of a dicentric chromatid and a U-shaped acentric fragment. It was also pointed out that each such event is comparable, with respect to time and frequency of occurrence, to mutations of other loci that produce recognizable phenotypic changes in genic action. It was concluded that *Ac* must give rise to a specific condition in certain cells of the plant that brings about an alteration in the mode of reproduction of the *Ds* locus in these cells during the mitotic cycle. This alteration eventuates in the production of breaks in the sister chromatids at the *Ds* position, as previously described. By genetical and cytological test methods, it was possible to place this *Ds* locus at a position demarcating the proximal third of the short arm of chromosome 9. Continued study, however, has revealed a type of event involving the *Ds* locus that appears to be responsible

for the origin and subsequent behavior of all *Ac*-controlled mutable loci. This event brings about a transposition of the *Ds* locus from one location in the chromosome complement to another. In its new position, *Ds* responds to *Ac* just as it did in its previous position. (The position of *Ds* in the short arm of chromosome 9, where it was first detected, has been designated the "standard position.") These transpositions of *Ds* are not infrequent. In the sporophytic tissues, they usually occur late in development and in individual cells of the plant. For transposition to occur, *Ac* must likewise be present. When *Ds* is transposed from its standard position to another position in the short arm of chromosome 9, the new location may be readily determined.

THE MECHANISM OF TRANSPOSITION OF THE *Ds* LOCUS

A number of cases of transposition of *Ds* are now under investigation. In some of these, a gross chromosomal alteration has accompanied the transposition of *Ds*. By cytological and genetical analyses of the cases involving gross chromosomal aberrations, it has been possible to reconstruct in considerable detail the events that must have occurred to bring about a transposition of the *Ds* locus. These events are similar in all analyzed cases and can be summarized as follows: During a mitotic cycle a condition may be produced at the *Ds* locus that results in the removal from one or both chromatids of a submicroscopic fragment of chromatin containing the *Ds* locus. Both ends of this fragment are unsaturated; and the mechanism of removal of the fragment may be a tearing process, since unsaturated ends, capable of fusion, are produced in each of the chromatids of chromosome 9 at the position where the fragment was situated. If, dur-

ing the same mitotic cycle, a spontaneous break occurs elsewhere in the chromosome complement, four additional broken ends may be present in the nucleus. Since any unsaturated broken end is capable of fusion with any other unsaturated broken end, a number of different consequences of fusion among the twelve broken ends can arise. If the spontaneous break occurs in the short arm of chromosome 9 at a position other than the *Ds* locus, several types of altered chromosomes 9 can be formed. These may have a deficiency, a duplication of a segment of the short arm—either in a normal or in an inverted order—or an inversion. On the other hand, fusions of broken ends can bring about a transposition of the *Ds* locus without an accompanying gross chromosomal rearrangement. If the spontaneous break occurs in one of the other chromosomes of the complement, a translocation between the short arm of chromosome 9, at the position of the *Ds* locus, and this other chromosome can be produced. A transposition of *Ds* may likewise accompany such an event. Examples of these various kinds of translocation and transposition have been found. Those involving transpositions of *Ds* within the short arm of chromosome 9, either accompanied or unaccompanied by gross chromosomal rearrangements, have been selected for continued investigation.

In the analyzed cases of transposition of *Ds*, the inserted segment of chromatin containing the *Ds* locus is not visible in its new position with the light microscope. It is also too small to affect detectably the percentage of crossing over in adjacent regions in plants heterozygous for the transposed *Ds* locus. Its detection in the new position is easy, nevertheless, because it behaves as it did in its former position; dicentric chromatids and acentric fragments may be produced by subsequent

breaks and fusions that now occur at this new position. Because it behaves in its new position as it did in its former position, transposition from this new position to still another position may occur subsequently.

The discovery of the transposition of the *Ds* locus, and the knowledge gained in determining the principal events responsible for it, have supplied the information needed for understanding the origin of other *Ac*-controlled mutable loci. It has also become possible to formulate a more direct approach for investigation of the primary effect of *Ac* on the *Ds* locus, wherever it may be, and to determine more fully the various changes that are known to occur at the *Ds* locus itself.

THE ORIGIN OF *Ac*-CONTROLLED MUTABLE LOCI

In Year Book No. 47 (1947-1948), the sudden appearance of an *Ac*-controlled mutable *c* locus was described. It was found in a single one of the tested male gametes produced by a plant having one *Ac* locus. This plant was also homozygous for a normal *C* locus and for *Ds* in its standard position. In this gamete, the action of the *C* locus had changed. It behaved thereafter like the known recessive (*c*) but, unlike this recessive, was capable of mutating back to a normal *C* action when *Ac* was present.

Study of the c^{m-1} locus has been of particular importance in revealing the factors associated with the origin and subsequent behavior of *Ac*-controlled mutable loci. It is now apparent that the mutable *c* locus arose when the *Ds* locus was transposed from its standard position to a position within or close to the normal *C* locus. This event occurred late in the development of the parent plant, and probably only in a single cell of this plant. No gross

chromosomal rearrangements accompanied the transposition. The chromosome 9 carrying this transposed *Ds* locus is morphologically normal. The transposition of *Ds* was recognized by the altered position of the chromatid breaks associated with *Ds* behavior and the concomitant disappearance of such events at the standard location. Both cytological and genetical test methods, used to determine the location of these breaks, were in agreement in placing the *Ds*-type activity at the known position of the normal *C* locus in the short arm of chromosome 9. In its new position, the *Ds* locus presumably inhibits the normal action of the *C* locus. The *C* locus, although present, does not appear to function, and as a consequence no aleurone color is produced. With respect to pigment formation, the tissue response is the same as that given by the known recessive allele, *c*, or by a deficiency of the *C* locus. This inhibited *C* locus, however, can mutate to a state that re-establishes its former action. This occurs only when *Ac* is also present in the nucleus. The restoration may be permanent. The restored *C* locus no longer shows unstable behavior in the presence of *Ac*, and it cannot thereafter be distinguished from a normal *C* locus. What occurs, then, at the inhibited *C* locus to restore its normal action?

As stated previously, the studies of a number of different transpositions of the *Ds* locus have shown that *Ds* may be removed from a chromatid and that the mechanism of removal involves compound chromatid breakage at this locus. The removed fragment containing the *Ds* locus has unsaturated broken ends, and the ends formed in the chromatid by its removal are also unsaturated and capable of fusion. It is known that *Ds* activity usually disappears completely at the c^{m-1} locus when a mutation from *c* to *C* occurs. The known mechanism of removal of *Ds* from a

chromatid, gained from a study of transpositions of *Ds*, suggests an explanation of these mutations. An event leading to removal of the inserted *Ds* segment from the *C* locus would give rise to two broken ends in the chromatid. Fusion of these broken ends would re-establish the former normal genic order, and remove the inhibitory action on the *C* locus induced by the inserted segment; and as a consequence a mutation from *c* to *C* would be evident. No further changes at this locus would occur, for no *Ds* locus would be present to produce them. The *C* locus would be completely normal again. If this primary event is responsible for the *c* to *C* mutations, it also explains why a few of these mutations are accompanied by detectable transpositions of *Ds*. Transpositions could take place if a spontaneous chromosome break, elsewhere in the chromosome complement, occurred in the same mitosis that removed *Ds* from the *C* locus.

The analysis of the events occurring when *Ds* is inserted into or close to the normal *C* locus has made it possible to interpret a previously puzzling aspect of *Ds* behavior at its standard location. At this position, two contrasting "states" of the *Ds* locus have long been recognized. When one of these states (state I) is in effect, the majority of mutational events occurring at the *Ds* locus result in the formation of a dicentric chromatid and a U-shaped acentric fragment. In the contrasting state (state II), there is a markedly lower frequency at this locus of breaks and fusions resulting in the formation of dicentric chromatids or other gross chromosomal rearrangements.

The above two contrasting states of *Ds* may be recognized when it is at the *C* locus (c^{m-1}). In the original isolate of c^{m-1} , a state I *Ds* locus was present. This was the same state of *Ds* that had been present in the chromosome before its trans-

position to the *C* locus. In kernels having this state of *Ds*, only a few mutations giving a *C* phenotype appear. This state of the *Ds* locus at c^{m-1} changes rather frequently, and by a single event, to one that is comparable to state II of the *Ds* locus at its standard position. The event is made evident by a greatly lowered frequency of dicentric chromatid formation. The rate of *c* to *C* mutations rises to a frequency that is comparable to the previous rate of dicentric chromatid formation. It has been determined that the *c* to *C* mutations are associated with a simultaneous loss of *Ds* activity. This relationship indicates that the change from a *c* to a *C* phenotype is associated with an event involving the *Ds* locus itself. A normal chromosome 9 having a fully active *C* locus but no *Ds* locus is the usual consequence. An interpretation of the event leading to a *C* phenotype has been given above. On this interpretation, the two contrasting states of the *Ds* locus reflect the relative frequencies of alternate consequences of the breakage events occurring at this locus. Both types of consequence are recognized when *Ds* is at the c^{m-1} locus, but only those giving dicentric chromatids or other gross chromosomal abnormalities are detectable when *Ds* is at its standard position. At this latter position, *Ds* may inhibit the action of the adjacent loci, but the inhibition may not be recognized because it results in no obvious change in a readily detectable phenotypic character. In this case, neither the inhibition of genic action brought about by the insertion of the *Ds* locus nor the release from inhibition following its removal would be evident. Detection of the frequency of breakage events at the *Ds* locus would be confined to the fraction that results in the formation of a dicentric chromatid and a U-shaped acentric fragment. This fraction may be high or low, depending on the state of the *Ds* locus.

That the time and frequency of aberrant events occurring at the *Ds* locus may be the same for each of these contrasting states will be indicated in a later section. The important difference is in the consequences of the breakage events, not in the frequencies of the events themselves.

The recognition of different states of the *Ds* locus makes it necessary to consider the factors responsible for the origin of these states and the conditions present in each. Two clearly distinguishable states of *Ds* have been described above. Other states of this locus have been recognized. When *Ds* is at the *C* locus (c^{m-1}), these several states are distinguishable, one from another, by the relative frequencies of the two main consequences of events occurring at *Ds*—that is, dicentric chromatid formation or *c* to *C* mutations. At the standard position, the comparable states are distinguished, one from another, by the relative frequency of only one of these consequences—dicentric chromatid formation. These states appear to be intermediates between the extreme state I and the extreme state II. It has been well demonstrated that a *Ds* locus giving a high frequency of dicentric chromatid formation may change at a single mitosis to one that gives a low frequency. A *Ds* locus giving a low frequency of dicentric chromatids, on the other hand, does not change to one giving a high frequency at a single mitosis. This change from extreme state II to extreme state I requires several stepwise events, reflected in the intermediate states. These observations would suggest that the individual states of the *Ds* locus are indications of the number of active *Ds* units that may be present in a small chromatin segment, and that the change from one state to another involves a change, in number and/or distribution of these units within the segment. Such changes might be expected to occur as one of the consequences

of the chromatid-breakage-and-fusion mechanism associated with the aberrant events occurring at the *Ds* locus. On this interpretation, it could be concluded that the extreme state II *Ds* locus has few *Ds* units and that the extreme state I *Ds* locus has many such units; for the mechanism could readily reduce the number of units through losses at a single aberrant mitosis, but would require a series of such mitoses to build up a large number of units.

The analysis of the origin and subsequent behavior of *Ds* at the *C* locus has served to clarify some other aspects of this study of mutable loci. Why did new *Ac*-controlled mutable loci arise in these stocks? Why did a normal "wild-type" locus suddenly behave as a mutable locus? What event occurred at the locus to bring about a mutation, that is, a change in phenotypic expression? The analysis of the origin and behavior of c^{m-1} has made it possible to approach these questions and to formulate a concise interpretation of the origin and behavior of the other *Ac*-controlled mutable loci. Inhibition of a locus, either qualitatively or quantitatively, by insertion of a foreign bit of chromatin can be followed by release of this inhibition if the foreign chromatin is removed, transposed, or in some manner altered in position with respect to the inhibited locus. The primary mechanism that allows for such changes at a locus is associated with compound chromatid breaks at the locus and subsequent fusions of the broken ends. In its initial aspects, it is only necessary to consider a single locus having the peculiar faculty of undergoing such breakage events, at whatever position it may be located, to account for the origin and behavior of many different mutable loci.

TRANSPPOSITION OF THE *Ac* LOCUS

During the past year, an extensive study of the inheritance behavior of the *Ac* locus

was undertaken. This study has established that *Ac* is inherited as a single unit. It shows typical Mendelian inheritance, with one important exception. This exceptional type of inheritance behavior is the same as that shown by *Ds*: transposition of the locus from one position in the chromosomal complement to another. Two or three per cent of the gametes of an *Ac Ac* plant may be derived from cells in which a transposition of *Ac* has taken place. These transpositions usually occur relatively late in the development of the plant. Plants derived from zygotes that have *Ac* loci in allelic positions in each of two homologous chromosomes may give rise to a few gametes with either (1) two *Ac* loci showing no linkage with one another, (2) two *Ac* loci completely linked or very closely linked, or (3) no *Ac* locus at all. When an *Ac* locus is transposed to a new position, it shows typical Mendelian inheritance at this new position. Linkage with known genic markers can be established. Here, again, exceptions may arise as the consequence of a few transpositions from this new position to still another position. The frequency of these transpositions is not high enough, however, to distort seriously the statistical data of linkage studies. It is likely that the mechanism producing transpositions of *Ac* is the same as or quite similar to that producing transpositions of *Ds*.

Ac itself is a mutable locus. It can be identified only by its action on *Ds*. Its mutations are made evident by changes in the time and frequency of *Ds* mutations. (The events at the *Ds* locus that result in either dicentric chromatid formation or a change in phenotypic expression of a *Ds*-inhibited locus will be termed "*Ds* mutations" in this account.) It is known that the number of *Ac* loci in the nucleus controls the time and frequency of *Ds* mutations. Increased doses of *Ac* loci (from 1

to 3 in the triploid endosperm) result in an increasingly delayed time of occurrence of *Ds* mutations. Similar changes in the mutational response of *Ds* will be registered after a somatic mutation in a single *Ac* locus. These responses indicate that some quantitative change may take place at the *Ac* locus when it mutates—probably an increase or decrease in the number of subunits at this locus. Thus, superimposed on those quantitative changes that can be produced by additions of whole *Ac* loci through controlled chromosome combinations in diploid tissues of the plant or in triploid tissues of the endosperm are those that can occur at a single *Ac* locus.

There is a ready method of identifying those kernels on the ears of *Ac Ac* plants that are likely to have a transposed *Ac* locus. This involves crossing plants having no *Ac* locus to plants having a single *Ac* locus in which the *Ac* state is known (determined by its effects on *Ds* in 1, 2, and 3 doses). The F_1 plants are selfed and the F_2 progeny grown. The F_2 plants are then crossed by plants having no *Ac* locus but carrying *Ds* at its standard location in each chromosome 9. The ears produced by the *Ac Ac* F_2 plants are selected, and an examination is made of the *Ds* mutation rates in the kernels. If, in the *Ac Ac* F_2 plants, no mutations have occurred at the *Ac* locus and no transpositions have taken place, all the kernels should show the same pattern of *Ds* mutations. In other words, the control of these *Ds* mutations should be the same, since all the kernels should have two *Ac* loci in the endosperm cells and all the *Ac* loci should be alike. The majority of the kernels on such ears do show a remarkable similarity in the pattern of expression of *Ds* mutations. A small percentage of the kernels, however, are markedly different. These exceptional kernels fall into three classes: (1) those showing no *Ds* mutations at all,

(2) those showing a few very late-occurring *Ds* mutations that suggest an increase in *Ac* dosage, and (3) those showing a time and frequency of *Ds* mutations that suggest a lowered dosage of *Ac*. A preliminary test was made in an attempt to determine the reason for the changed responses of *Ds* in the kernels of types (1) and (2). Twenty-five such kernels were selected from these ears, and plants were grown from them. Tests were conducted to determine (1) the presence or absence of *Ds*, (2) the presence or absence of *Ac*, and (3) the action of *Ac*, when present, in one and two doses. Eleven of the plants arising from these selected kernels gave no evidence of *Ac* at all; the *Ac* locus was either absent altogether or completely inactive. Ten other plants had two independent, nonlinked *Ac* loci. In four plants, *Ac* was inherited as a single unit; but this unit, in a single dose, produced the same effect on *Ds* mutations that two units of the original *Ac* locus, from which it was derived, had produced.

One type of event, the transposition of *Ac*, will account for these results. If, in these *Ac Ac* F_2 plants, transposition of one of the *Ac* loci occurred in a meiotic or premeiotic mitosis, two *Ac* loci would still be present in the nucleus, but they would no longer be allelic with respect to position in the chromosomal complement. If the transposed *Ac* locus were inserted into a nonhomologous chromosome, meiotic segregations could give rise to gametes with either (1) one *Ac* locus, in its original position or its new position, (2) two *Ac* loci, one in each of two nonhomologous chromosomes, or (3) no *Ac* locus. Transposition within the same chromosome (or homologue), or insertion of the *Ac* locus of one chromatid adjacent to the *Ac* locus of the sister chromatid, would give comparable meiotic segregations with respect

to the production of gametes with two *Ac* loci or with no *Ac* locus.

In the given cross, the kernels arising from the megaspores having no *Ac* locus would show no *Ds* activity; for no *Ds* mutations occur without *Ac*. Tests for *Ac* in the plants arising from these kernels would be negative, because no *Ac* locus would be present. Kernels developing from megaspores receiving a single *Ac* locus, either in its original position or transposed but unmodified in its action, would show the characteristic effect on *Ds* mutations produced by the *Ac* locus when two are present in the endosperm. (It should be recalled that the female parent contributes two nuclei to the triploid endosperm tissue, and the male parent one.) Those developing from megaspores with two *Ac* loci, either linked or situated in different chromosomes, would give rise to endosperms with four instead of two *Ac* loci. It is known that increases in the dose of *Ac* will delay the time of appearance of *Ds* mutations, and that this effect is proportional to dosage—the higher the dose, the more effective the delay. With four doses of *Ac* instead of the usual two, the delay may be so effective that either no *Ds* mutations will occur during the development of the tissue or only a few will occur very late in the development of the endosperm. In either case, the kernels having such increased doses of *Ac* will be strikingly different in appearance from the majority of kernels, that is, those with two *Ac* loci in their endosperm cells. It was this striking difference in appearance of a few kernels on these ears that allowed the selection to be made. The analysis of the *Ac* composition of the kernels has led to the conclusion that they develop from ancestor cells in which a transposition of *Ac* has occurred.

For comparison, plants were grown from some of the kernels on these F_2 ears that

showed the characteristic type of *Ds* mutational response known to be associated with the presence in the endosperm of two *Ac* loci. Tests of the *Ac* constitution of these plants gave the expected results. One *Ac* locus was present in each of the tested plants, and its control of the time and frequency of *Ds* mutations, in one or two doses, was similar to that in the parent plant.

These studies have been expanded during the summer of 1949; but the results of the preliminary tests are sufficient to indicate the factors responsible for apparent exceptions to the expected Mendelian inheritance of *Ac*. They have also made possible an interpretation of one of the several kinds of event that occur during the development of the plant or of the endosperm to bring about pronounced changes in the action of *Ac* on *Ds*. These changes are registered by the appearance of precise sectors showing altered *Ds* responses. Tests are now being conducted to distinguish between changes in state of the *Ac* locus—that is, between changes in quantitative action of an *Ac* locus that is inherited as a single unit, and changes that are caused by an increase in numbers of such loci after transposition of *Ac*, as outlined above. The phenotypic effects of these two types of change overlap, but the causative series of events, although related, are nevertheless separable.

The mechanism responsible for transposition of the *Ac* locus has not been analyzed. It is thought likely to be the same as or similar to that producing transpositions of *Ds*. If so, some of the transpositions of *Ac* should be associated with chromosomal rearrangements. A chromosomal translocation was recognized in one of the cases cited, but it has not yet received adequate analysis.

THE ACTION OF *Ac* ON THE MUTABLE LOCI IT CONTROLS

It has been emphasized repeatedly that *Ac* controls the occurrence of *Ds* mutations and that its quantitative levels control the time and frequency of these mutations. In this report, it has been shown that the mutable c^{m1} locus is merely a transposed *Ds* locus situated at or close to the *C* locus. The analysis of this c^{m1} locus and of its origin from a transposition of *Ds* has suggested that all *Ac*-controlled mutable loci arise from transpositions involving, originally, only one *Ds* locus. According to this interpretation, *Ac* does not control the mutability of many different loci, but only the mutability of a single locus—the *Ds* locus—wherever it may be situated in the chromosomal complement. Mutations of *Ds* in these various positions may result in changes in phenotypic expression that are strikingly different. The change in phenotype, in any one case, depends on the kind of locus that has been inhibited by the insertion of *Ds*. In their normal action, these various *Ds*-inhibited loci must control quite different chemical processes. The events at the *Ds* locus that result in a return to partial or complete action of the inhibited locus must therefore involve a different series of changes in chemical processes in each case. Without an integrative understanding of the events that occur at such mutable loci, it would be difficult to understand why *Ac* should control the mutability of loci concerned with such unrelated processes, and why each such locus should respond to a particular *Ac* locus and dosage in an exactly comparable manner. There is no difficulty, on the basis of the given interpretation, in appreciating the apparent nonselectivity of control of mutable loci by *Ac* and the similarity in response of these mutable loci to changes in *Ac* state and dosage.

In order to obtain more specific information about the nature of the action of *Ac* (other than its known effects in producing chromatid breaks at the *Ds* locus and controlling the time and frequency of these breaks), combinations of *Ds* loci at various positions in the short arm of chromosome 9 have been made. These combinations were made in an attempt to answer the following question: Does *Ac* produce a cellular or nuclear condition in a certain cell, at a certain time in development, to which all *Ds* loci will respond? An instructive example for this purpose is a combination of c^{m-1} (*Ds* at or close to the *C* locus) with *Ds* at its standard location. If a plant carrying c^{m-1} and *wx* in its chromosomes 9 is crossed by a plant carrying c^* (stable *c*, nonmutable with *Ac*), *Wx*, and *Ds* (standard location, to the right of *Wx*), kernels will be produced that are $c^{m-1} wx/c^{m-1} wx/c^* Wx Ds$. This combination should show whether or not mutations in the several *Ds* loci will occur at the same time in the same cell, and whether this response will be of the same order with one and with more doses of *Ac*. Simultaneous mutations would be revealed in these kernels provided an extreme state II *Ds* locus were present at c^{m-1} (mutation from *c* to *C* and few if any dicentric chromatid formations), and an extreme state I *Ds* locus were present in the $c^* Wx Ds$ chromosome (high rate of dicentric chromatid formation). If all *Ds* loci respond to some particular developmental change that is brought into being by the presence of *Ac*, then when this changed condition arises in a cell, a mutation of *Ds* at the c^{m-1} locus should give a *C* phenotype in the descendant cells. A mutation at the *Ds* locus in the $c^* Wx Ds$ chromosome should also occur. A *wx* phenotype would then appear in the descendant cells, because a *Ds* mutation in the $c^* Wx Ds$ would produce a dicentric

chromatid and a U-shaped acentric fragment; this acentric fragment would carry the *Wx* locus, and consequently *Wx* would be lost from the nuclei during a mitosis. The effects produced by such simultaneous mutations of the several *Ds* loci should be visible in the mature kernel. Colored areas (the *c* to *C* mutations) should appear, and the underlying starch should be *wx*. Also, the borders of the sectors having both of these altered phenotypes should correspond exactly. In the examined kernels having these given constitutions, a high percentage of the *C* areas had underlying *wx* starch, and the borders of the sectors did exactly correspond. Exceptions were expected, and a number were observed. Some examples were: *C* areas with underlying *Wx* starch, *wx* areas with overlying colorless aleurone, *C* areas with only half of the underlying sector composed of *wx* starch, or *wx* areas with only half of the overlying aleurone layer showing a *C* phenotype. It is hoped that an extended analysis of the various classes of exceptional areas in these kernels will reveal the more unusual consequences of the events that occur at the *Ds* loci in these mutation-producing mitoses, and the resultant organization in the two affected sister chromatids.

Tests have also been constructed to determine the relation between the mutations of *Ac* and those of *Ds*. Although the analyses of these tests are incomplete, it seems apparent that *Ac* tends to mutate in the same cell in which a *Ds* mutation is occurring, or in an immediate ancestor cell. The combined evidence suggests that some condition, under the control of the *Ac* locus and depending on its state and dosage, must develop in specific cells at specific times, to produce a mutational response (chromatid breaks) at *Ds* loci as well as at the *Ac* locus itself. The consequences of such mutation are the observed changes in

genic action, transpositions or losses of *Ds* or *Ac*, and production of gross chromosomal rearrangements with or without accompanying transpositions of *Ds* or *Ac*.

MUTABLE LOCI c^{m-2} AND wx^{m-1}

The *Ac*-controlled mutable loci c^{m-2} and wx^{m-1} were described in Year Book No. 47. A few salient facts and conclusions based on the continued study of these loci are as follows: Both loci express their mutations quantitatively. A series of alleles derived from such mutations, which show gradations of quantitative expression, have been selected for study. When *Ac* is absent, a particular expression of an allele can be held constant, for no somatic mutations of these alleles occur. When *Ac* is present, the alleles may continue to mutate to either higher or lower levels of quantitative expression. For a study of the action of any one allele, therefore, it is important that no *Ac* locus be present.

It has been determined that chromatid breaks may occur at these two mutable loci; in this respect, they are similar to c^{m-1} . Both c^{m-2} and wx^{m-1} were isolated from stocks known to have a *Ds* and an *Ac* locus. Unlike c^{m-1} , they were not detected at the time of their origin. It is therefore impossible to reconstruct the particular events associated with their origin from a normal *C* locus and a normal *Wx* locus. The presence of *Ds*- c^{m-1} behavior at these mutable loci points to a mechanism similar to the one associated with the origin of c^{m-1} .

In the case of c^{m-2} , the position of insertion of *Ds* into or adjacent to the *C* locus may differ from its position of insertion in c^{m-1} ; for two qualitatively different types of phenotypic expression of the *C* locus result from mutations of c^{m-2} , whereas only one type regularly follows mutations of c^{m-1} . Both types of qualita-

tively distinguishable mutations at c^{m-2} result in pigment formation in the aleurone layer. Within each of the two qualitative types there occurs a series of mutants showing various degrees of quantitative expression. The color intensities produced by the different mutants of both types range from a faint pink to a deep red (in *pr pr* constitutions). The two series of mutants are distinguished from each other mainly by the fact that a different diffusible substance (or substances) is produced by the members of each. Both substances are concerned with pigment formation. The diffusible substance produced by type 1 mutants may be utilized by a cell having a normal *C* locus, or by a cell having a type 2 mutant, to intensify the color of the cell pigment. The normal *C* locus and the type 2 mutants, on the other hand, both produce a diffusible substance that can be used by type 1 mutants to intensify pigment color. Thus, the type 2 mutants and the normal *C* locus are much alike; they both produce a diffusible substance that type 1 mutants can use, and they both can use a diffusible substance produced by type 1. This relationship suggests that a normal *C* locus is probably responsible for the production of at least two diffusible substances, both of which are required for pigment formation. It also suggests that the dosage responses noted for the normal *C* locus may be the consequence of a limited production of one of these substances by a single *C* locus: the more *C* loci were present, the more of this substance would be produced and the deeper would be the pigment color. The quantitative grades of expression of the alleles within the two types of mutations arising from c^{m-2} may reflect the relative quantities of the two substances produced by individual members of a type—limitations in the production of one of these substances conditioning the amount of pig-

ment that can be formed, and thus the depth of color that can appear.

The conclusions derived from study of c^{m-2} regarding the action of the normal C locus are noteworthy, in that they consider a double function of a single unit in inheritance. This unit, concerned with pigment production in the aleurone layer of the endosperm, appears to be composed of at least two qualitatively different subunits, both of which determine the production of substances required for pigment formation. It is possible that this C locus behaves as a unit in inheritance not only because all the subunits are needed for the production of pigment, but also because a particular spatial relation of the units at the locus is required to assure a definite sequence of reactions.

Mutations of the wx^{m-1} locus have been similarly instructive in considering the action of the normal Wx locus, but for reasons other than those just discussed for c^{m-2} . Here, alleles showing various quantitative levels of expression are produced by mutations of wx^{m-1} . The levels are expressed by the percentage of amylose in the starch component of the endosperm cells. When only the recessive, wx , is present, no recognizable amylose starch is produced. The selected alleles derived from mutations of wx^{m-1} form a series in which a single dose (Wx allele, wx , wx) produces quantities of amylose ranging from very little (less than 1 per cent) to as much as the normal Wx locus produces in three doses. Chemical analyses of the percentages of amylose starch produced by several of these alleles have been conducted by Miss Ruth Sager and Dr. Charles O. Beckmann, of Columbia University. These analyses have shown that the type of color reaction produced by staining with iodine is a relatively reliable indication of the approximate percentage of amylose present.

Interest in this case centers not so much

in the appearance of alleles having lower activity than the normal Wx locus as in those having higher activity than the normal locus. Is the normal Wx locus partially inhibited, or do the Wx alleles showing greater than normal activity arise from duplications of the locus? In Ac -carrying plants, the chromatid-breakage-and-fusion mechanism associated with mutations at the wx^{m-1} locus or its intermediate alleles should give rise, in some cases, to duplications or multiplications of units of the Wx locus. It is hoped that a study of the different amounts of amylose produced by sister chromatids after mutation of wx^{m-1} , or one of the intermediate alleles, will furnish some information with reference to this question.

CONCLUSIONS

The purpose of the foregoing sections has been to indicate the progress made during the past year in attacking fundamental aspects of the origin and behavior of Ac -controlled mutable loci. It was concluded that only two loci are involved in all these cases: the Ds locus and the Ac locus. The origin and subsequent behavior of newly arising mutable loci depends on the transposition of a Ds locus and its insertion into (or adjacent to) a normal locus, and on the constitution of this inserted Ds locus. The genic action of a normal locus may be inhibited by such an insertion. Subsequent events at this new position may remove the inserted segment and its inhibitory action altogether; or changes in the constitution or position of the Ds locus may result in changes in the degree of inhibition of the affected locus. It was also concluded that the events occurring at Ds during a mutation-producing mitotic cycle result in compound chromatid breaks at this locus, and that the observed consequences depend on subsequent fusions of the broken ends.

The fusion phenomenon, of utmost importance in these cases, calls for no new interpretations, since the fusion of newly broken (unsaturated) chromosome ends has been well investigated and could be anticipated.

Both *Ac* and *Ds* are mutable loci, for their mode of action changes as the consequence of events occurring at these loci in certain cells of the plant. Like *Ds*, *Ac* also undergoes transposition from one location in the chromosomal complement to another. The mechanism of transposition, although not directly analyzed, is possibly similar to that associated with the transpositions of *Ds*. The evidence also indicates that changes in *Ac* as well as *Ds* are associated with chromatid breakage and fusion. It is necessary to determine, then, the nature of the events occurring at these two mutable loci, during a particular mitotic cycle, that will result in the observed breakage-and-fusion phenomena. Unquestionably, these events are primarily responsible for all the observed changes at these mutable loci. It is suspected that they are associated with some aberration in the mode of reproduction of a particular type of molecule in the chromosome during a mutation-producing mitotic cycle. Both *Ac* and *Ds* are assumed to have such molecules. If the aberration involves a chemical bonding of the newly formed molecule with the original molecule, which holds at least until after the forced separation of sister chromatids during the prophase period, a rupture of the chromatid could occur at the affected locus during this separation period. It is known that the bonds holding the molecules together in a linear order in the chromosome may be ruptured by mechanical pull, and that the broken ends so produced are unsaturated and capable of fusion with other unsaturated broken ends. It is therefore necessary to assume, in this interpretation,

that the bond connecting the newly formed molecule with the original molecule is stronger than the bond holding the molecules together in linear order.

The study of transpositions of the *Ds* locus has shown that a rupturing mechanism of this type, or at least one that leads to similar consequences, must be involved. It has been established that the transposition phenomenon is associated with chromatid breakage; the *Ds* locus is inserted into a position where a spontaneous break has occurred. The transposition phenomenon is readily explained if it is assumed that break-producing events at the *Ds* locus may sometimes result in the tearing-out of a minute fragment containing *Ds* and having two unsaturated broken ends. The insertion of *Ds* into a new position would result merely from fusion of unsaturated ends. If the broken ends arising from the spontaneous break are labeled 1 and 2 and those of the fragment 3 and 4, the fusion of 1 with 3 and 2 with 4 would accomplish the transposition. The above-described process of mechanical rupture of the chromatid at the *Ds* position could result in just such a torn-out fragment. The consequence of any one rupture would depend on the type of fusion of broken ends that followed. Not only could transpositions occur, but the *Ds* locus could be lost altogether, or two *Ds* loci could enter one chromatid, leaving none in the sister chromatid. Such duplications (altered states of *Ds*) could, in turn, initiate a series of new consequences when the aberrant type of event, leading to chromatid rupture, again occurred in a descendant of this chromatid.

The analysis discussed in this report of the factors associated with the origin and behavior of *Ac*-controlled mutable loci in maize has led to a relatively simple interpretation of the nature of the events responsible for changes in action of the genes

involved. The types of phenotypic change that follow mutations of non-*Ac*-controlled mutable loci are similar to those shown by the *Ac*-controlled mutable loci. It is quite possible that the same or similar events are primarily responsible for these changed phenotypes also.

Mutable loci have been described in a number of organisms. Many of them show changes in phenotypic expression similar to those now being observed in maize. The events responsible for changes in expression of genic action may be simi-

lar in these organisms to those occurring in maize. The investigations described in this report cast doubt on interpretations that postulate a "true gene mutation," that is, a chemical change in a gene molecule, resulting in a changed specificity of its active product. Phenotypic change may well be related to inhibition of the action of a normal gene followed by partial or total release of this inhibition, together with such duplications or deficiencies of the locus as could be produced by the mechanism outlined above.

THE GENE

M. DEMEREC, B. WALLACE, E. M. WITKIN, AND G. BERTANI

During the past year our group has been engaged in studies of a number of problems dealing with gene mutations. In *Escherichia coli* an extensive study was made of the genetic mechanisms responsible for changes to streptomycin resistance and dependence, and reversions from dependence to nondependence. This study revealed a complex system of different mutations that can be recognized by their effect on several other properties in addition to streptomycin resistance. Results so far suggest that the majority of these mutations are due to changes either in a single gene locus or in adjacent loci. The effect of sodium nucleate on mutations in *coli* was studied; and the resistance patterns for aureomycin, chloromycetin, and neomycin were investigated. Survey studies of the mutagenic action of chemicals were continued, using both *E. coli* and *Drosophila*.

We were assisted in this work by Misses J. Flint, E. Lively, H. Spring, and L. Hahn, Mrs. J. Buchanan, Mr. R. Millemann, and Mr. W. Belser, and during the summer by Miss Rada Demerec, of Swarthmore College, and Mr. Norton Zinder, of the University of Wisconsin. The work was

aided by a grant from the American Cancer Society, recommended by the Committee on Growth of the National Research Council.

GENETICS OF STREPTOMYCIN RESISTANCE IN *ESCHERICHIA COLI*

Our earlier work (Year Book No. 45, 1945-1946, pp. 152-153) showed that bacteria resistant to streptomycin originate through mutations, and also that completely resistant mutants may be obtained in one step from sensitive bacteria. Even though the rate of mutation to complete resistance is very low, it is not difficult to measure, since several billion bacteria may be plated on a Petri dish with medium containing streptomycin and only the resistant will grow to form colonies. As in the earlier studies of mutation to bacteriophage resistance, extremely large numbers of individuals can be used in these experiments, and thus very exact determinations of spontaneous and induced mutability can be made. Therefore, investigations of streptomycin-resistance mutability were continued, with the purpose of developing another method in mutation studies to

complement the phage-resistance method, which we have been using with good success since 1942.

Rate of spontaneous mutation to resistance. Determinations were made by M. Demerec and E. Lively of the rate of spontaneous mutation to streptomycin resistance, using the method of independent cultures developed by Luria and Delbrück. In each experiment about one hundred broth cultures of 1 ml. each were grown to saturation, and the proportion of cultures without mutants was determined by plating the whole contents of each tube into agar-broth medium containing 25 μ g. per milliliter of streptomycin. In addition, 5 cultures in each experiment were assayed to determine the average number of bacteria present. Using Delbrück's formula, mutation rate was calculated in four experiments as follows: with strain B/r, 0.73 and 1 per 10^9 ; with strain B/1, 1.3 per 10^9 ; and with strain B/6, 2.6 per 10^9 . From these data it may be concluded that for the B strain the rate of mutation to streptomycin resistance, using concentrations of 25 μ g. per ml., is about 1×10^{-9} .

It has been found that a portion of streptomycin-resistant mutants are dependent on streptomycin; that is, they require it in order to divide. About 60 per cent of mutants in the B/r strain are of this dependent type.

Spontaneous reversions from dependent strains. Dependent mutants are able to pass through only a few divisions on medium without streptomycin. The number of divisions depends on the mutant itself, on the concentration of streptomycin on which it grew, and on the degree of crowding of the cells on the culture. Therefore when dependent bacteria are plated on medium not containing streptomycin, they will soon stop growing; but any mutant to nondependence (a reversion) that occurs during these divisions

will grow and form a colony. Thus when information is available about the number of dependent bacteria plated, the number of divisions passed through on medium without streptomycin, and the number of nondependent colonies appearing, it is possible to calculate the mutation rate from dependence to nondependence. Since large numbers of bacteria can be used, this method is suitable for studies of low rates of spontaneous and induced mutations.

The experimental studies of spontaneous reversion rates were carried on by M. Demerec, G. Bertani, and E. Lively.

The behavior of strain Sd-4 (B/r/Sd-4) has been analyzed in detail. The number of residual divisions on plain mutant agar for Sd-4 bacteria grown on 25 μ g. of streptomycin per ml. was determined by washing the plate with 10 ml. of broth and assaying the suspension. The effect of number of bacteria plated on the number of residual divisions has also been studied. When 10^7 to 5×10^7 bacteria are plated, the number of divisions they pass through is approximately 3.5. These divisions are completed in about 12 hours at 37° C. After this time the bacteria stop dividing, but continue to grow in length, forming filamentous polynucleate cells ("snakes"). A high percentage of these long cells are still "alive" (i.e., able to recover and grow normally if streptomycin is added) after 1 to 2 days. Two facts seem to indicate that mutations can take place in the filamentous stage: (a) new mutant colonies are still appearing after as much as 5 days; (b) when cells are irradiated after completion of residual divisions, the number of mutant colonies increases. This means that an estimate of rate of mutations from dependence to nondependence calculated from the number of living bacteria present on the plate will be too high. Under the conditions stated above for streptomycin concentration and crowding, the average

number of reversions, scored after 6 to 7 days of incubation at 37°C ., is 36.8 ± 2.8 (average from 17 experiments; 7 to 20 plates per experiment) per 10^8 plated bacteria. Taking into account the residual divisions the bacteria pass through, an estimate of the rate of mutation from streptomycin dependence to nondependence per bacterium per division can be calculated as 3.7×10^{-8} . This does not take into account the nuclear divisions occurring during formation of filaments. Among the mutants obtained, some (about 25 to 30 per cent for this particular strain) are resistant, some are sensitive. Sensitive mutants are obviously selected against as long as the dependent strain is cultured in the presence of streptomycin. Resistant mutants might theoretically form a "background" in Sd cultures (as happens with mutants resistant to phages); but timing of the appearance of the mutant colonies does not yield any evidence of such "background." In the presence of dependent bacteria and streptomycin, resistant mutants also are probably selected against.

Patterns of residual growth, rate of mutation, and ratio of resistants to sensitives among reversions are different for different dependent strains.

Mutations induced by irradiation. An extensive series of experiments, using ultraviolet rays of wave length 2537 Å and X-rays, was carried on by M. Demerec and E. Lively to determine the rate of induction of mutations from B to resistance and of reverse mutations from dependence to nondependence. Previous work with radiations (see Year Book No. 44, 1944-1945, pp. 115-116) had shown that induced mutations to phage resistance are of two types: the so-called "zero-point" mutations, which are expressed before the irradiated bacteria have passed through a cell division; and "end-point" mutations, which are not expressed until after at least one

cell division has taken place. It had also been found (see Year Book No. 45, pp. 143-144) that with X-rays the mutation rate is directly proportional to the dose, giving a single-hit curve, whereas with ultraviolet rays there is a disproportionately rapid increase with increased dose, indicated by a multiple-hit curve.

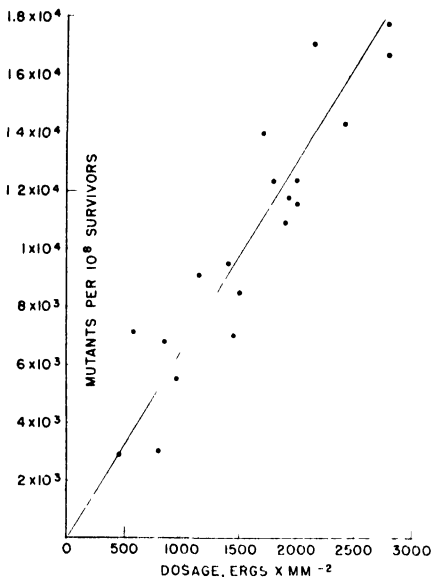


FIG. 1. Reverse mutants induced in a streptomycin dependent strain (B/r/Sd-4) of *Escherichia coli* by various doses of ultraviolet rays.

This year's experiments showed that in the streptomycin-resistance system zero-point mutants do not appear, either among the resistant mutants or among the reversions. Studies of the relation between dosage and mutation rate, made with reversions in the streptomycin-dependent strain, demonstrated that increase in mutation rate is proportional to increase in dosage in material treated either with ultraviolet rays or with X-rays (figs. 1, 2).

Studies of induced mutation from sensitivity to resistance indicated that not all

the induced mutants show up by the time surviving bacteria have doubled in number. This may be due to the same cause as the delay observed in the expression of end-point mutations to phage resistance (see Year Book No. 44, pp. 115-116).

Mutations induced by chemicals. It was found convenient to use induction of reversions from streptomycin dependence to nondependence as an index in studying the mutagenic properties of chemicals.

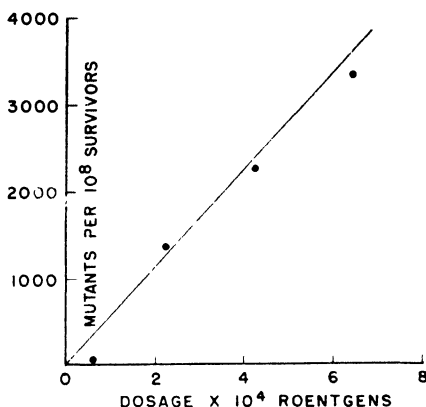


FIG. 2. Reverse mutants induced in a streptomycin-dependent strain (B/r/Sd-4) of *E. coli* by various doses of X-rays.

Resting bacteria of the dependent strain Sd-4 were treated with a certain chemical in aqueous solution, plated on broth agar, and incubated for 7 days; then the number of mutants on each plate was determined. Occasionally the treatment caused the bacteria to clump; and to avoid the variable that might thereby be introduced, the treated bacteria were examined under the microscope and used only if clumping was not evident. Untreated controls were included in each experiment.

This test—because of the difficulty of checking the amount of residual growth—is not the most favorable for quantitative

studies of relations between mutation rate, concentration of chemical, and length of treatment. It is probably the most expedient, however, when the main problem is whether or not a substance is mutagenic.

These experiments were done by G. Bertani, M. Demerec, Jessie Flint, and Eileen Yongen, who is working under a grant from the Jane Coffin Childs Memorial Fund, administered by the Biological Laboratory.

Chemical substances to be tested for mutagenic potency were chosen according to two main criteria: either because they had shown definite or probable mutagenicity in earlier genetical tests (induction of lethals in *Drosophila*, induction of resistance to phage T1 in *E. coli*, etc.), or because they represented particular chemically defined groups of substances. The data collected for various chemicals are summarized below.

Formaldehyde: Previously shown to be mutagenic in *Drosophila* feeding-technique experiments. Streptomycin test showed definite mutagenicity, even at survival levels as high as 60 per cent. Tenfold increases in number of mutations, as compared with controls, were detected in some experiments. Preliminary experiments showed that treatment with formaldehyde has no considerable effect on residual growth.

Acriflavine: Previously shown to be mutagenic in phage-resistance tests. In the present test, mutagenic effect could be detected at a survival level of less than 1 per cent.

Phenol group: Phenol is known to be mutagenic in *Drosophila*, when the treatment is applied by means of special transplantation techniques. With the streptomycin test it was also positively mutagenic, in a survival range of 0.5 per cent to 34 per cent, with increases up to tenfold in number of mutations as compared with controls. Two other substances, chemically closely related to phenol, were tested, namely, picric acid and alpha-dinitrophenol. Both showed mutagenicity of the

same order and in the same survival range as phenol.

Caffeine: Known to be mutagenic for molds. Preliminary experiments showed positive results in the streptomycin test.

Sodium desoxycholate: Previous phage-resistance tests showed a very low degree of mutagenic potency. In the present test, no induction of mutations could be detected. This may indicate that the streptomycin method of testing is less sensitive than the phage-resistance method.

Ethyl carbamate (urethane): Known to be mutagenic for *Drosophila*. In the streptomycin test, definitely mutagenic when survival is less than 10 per cent, weakly mutagenic when survival is as high as 60 per cent.

Ammonia: Detectably mutagenic only when survival is lower than 2 per cent. The same effect seems to be typical of ammonium chloride.

Inorganic acids: Phosphoric, hydrochloric, nitric, and sulfuric acids were tested. None showed mutagenic activity.

Organic acids: Acetic, formic, and lactic acids were tested. Results with this group of substances were very irregular and are still in progress. Formic acid is probably weakly mutagenic.

Alkalis: Sodium hydroxide and potassium hydroxide were tested. Neither is mutagenic.

Heavy metal salts: Copper sulfate, mercuric chloride, and silver nitrate were tested. At high survival levels (more than 10 per cent) none of them is mutagenic. Experiments with low survival ranges (which are difficult to obtain with short periods of treatment, such as have commonly been used in these experiments) are still going on.

Ferrous chloride: This compound gave a very high number of induced mutations at high survival levels. Mutagenic potency compares well with that of nitrogen mustard and radiations.

Mutation pattern of the streptomycin-resistance system. Mutants of the B strain of *coli* that are resistant to streptomycin (B/S) or dependent on streptomycin (B/Sd) may be isolated by plating large num-

bers of the bacteria in medium containing streptomycin. Reverse mutants (R) from the dependent strain may be isolated by growing B/Sd on medium lacking streptomycin. By the same process of selection, resistant and dependent mutants can be picked up from the reversions, and from these second-order dependents another set of reversions may be obtained. By continuing the procedure, resistant mutants and reversions of higher orders may be produced. M. Demerec, Ethelyn Lively, and Helen Spring studied such a chain of mutational changes through four orders, and made an extensive analysis of 163 dependent mutants and 120 reversions isolated in this series of experiments. The following properties were studied: (1) mutation rate, (2) mutation pattern (i.e., proportions of B/S and B/Sd mutants and R and S reversions given by the different R's and B/Sd's), (3) growth rate, (4) biochemical deficiencies, which frequently are connected with these mutational changes, (5) sensitivity to ultraviolet radiation, and (6) dependence on certain degradation products of the streptomycin molecule.

From the results of all these tests together, it was evident that hardly any two of the mutants studied were alike; and we used only six out of many possible criteria to detect differences between them. This means that a reversion from a B/Sd to an R does not come about by a reversal of the chemical reaction that originally produced the B/Sd ($B \rightleftharpoons B/Sd$), but must originate through a change independent of the original one. Therefore there must be a considerable number of independent reactions that give rise to either streptomycin-dependent, streptomycin-resistant, or streptomycin-sensitive mutants.

Genetic mechanisms of the resistance pattern. An effort was made to find out whether one or several gene loci are involved in the control of reactions in the

streptomycin-resistance system. The most direct way of solving such a problem is to determine genetic relationship by intercrossing. Unfortunately, this cannot be done with bacteria, at least not with the B strain of *E. coli*. Lederberg, however, working with the K-12 strain of *coli*, has shown that if two lines, each carrying several heritable characteristics, are plated together, there occur interchanges between the two sets of characters comparable to the crossing over observed in higher organisms. He has worked out a technique whereby the amount of crossing over can be determined and the distances between loci calculated. If no recombination is obtained between two characters, this indicates either that their genes are in the same locus (allelic) or that they are located in closely adjacent loci.

We have partially repeated with the K-12 strain the experiments made with our B strain, and have found that they have a similar pattern of resistance to streptomycin. Intercrosses were made between six mutants of K-12/S and four mutants of K-12/Sd, all of different origin and some having special properties. The results indicate that these mutants are either alleles or located close together. The crosses were carried out by Mr. Norton Zinder, a graduate student of Dr. Lederberg, who spent six weeks with us during the summer. The work is now being extended to additional mutants of higher orders.

Correlation between spontaneous and induced mutation rate. It has already been mentioned that B/Sd mutants differ in their rates of reversion. For example, reverse mutations were observed to occur in Sd-4 with a frequency of about $3.7 \text{ per } 10^7$ plated bacteria, whereas in Sd-12 only one mutant was found among 4.72×10^{10} bacteria. Experiments by Demerec and Lively showed that ultraviolet treatment that in-

duced 6600 mutants in Sd-4 did not induce any in Sd-12.

Streptomycin dependence. In our studies of the streptomycin-resistance system we have accumulated a large collection of streptomycin-dependent strains of separate origin. Of these, 124 were tested by Demerec and William Belser for ability to grow on two streptomycins (dihydrostreptomycin and mannosidostreptomycin) and on five degradation products of the streptomycin molecule: (1) tetrahydroanhydrostreptobiosamine hydrochloride, (2) streptobiosamine hydrochloride, (3) streptidine dihydrochloride, (4) streptidine sulfate, and (5) streptamine dihydrochloride. The two streptomycins, and degradation products (1), (2), (3), and (5), were received from Dr. Josef Fried, of E. R. Squibb & Sons; and degradation product (4) was received from Dr. Amel Menotti, of Bristol Laboratories, and Dr. Karl Folkers, of Merck & Company.

Both the streptomycins were adequate to supply the deficiency in each of the 124 dependent strains. Degradation products (3), (4), and (5) were not adequate to supply the deficiency in any of our strains; whereas 44 strains were able to grow on (1) but not on (2), 9 strains on either (1) or (2), and 1 strain on (2) but not on (1). Considerable differences were observed among the various Sd forms with respect to rate of growth on these compounds, as well as on streptomycin.

General considerations. The analysis of the streptomycin-resistance system indicates that here a series of reactions is controlled by what appears to be a single gene locus. One change in this locus produces a mutant resistant to streptomycin; another change in the same locus produces a mutant dependent on streptomycin; another, a resistant slow grower; still another, a dependent biochemically deficient mutant; and so on. It appears that this par-

ticular locus controls a series of interrelated reactions—a chain of reactions—the end result being determined by the point at which the chain is interrupted or broken by the gene change.

This chain of reactions may be lineal; or it may be branched—that is, some of its links may serve as the starting points of new reaction chains. Our results indicate that, after this chain has been interrupted by a mutation, continuity is re-established (i.e., reversion occurs) not through a repair in the interrupted link, but rather through a change at some other point, which either re-establishes the original reaction or induces the development of a product to replace the one suppressed by the mutation.

According to information now available, this interrelated system of reactions controls the following properties: resistance to streptomycin; dependence on either streptomycin or some part of the streptomycin molecule; resistance to radiations, mustard compounds, and penicillin; some not yet identified biochemical deficiency; mutation rate; and mutation pattern. It is not associated with resistance to the seven phages of the T series. We have tested about 500 streptomycin-resistant and -dependent mutants with phages of the T series and have detected no instance of a change involving both resistance to streptomycin and resistance to phages. This suggests either that bacterial cells possess several completely independent systems of interrelated reactions, or that there is only rarely a connection between the reactions involved in different systems.

BACTERIAL RESISTANCE TO AUREOMYCIN, CHLOROMYCETIN, AND NEOMYCIN

Our earlier work (see Year Books No. 43, 1943-1944, pp. 109-110; No. 45, 1945-1946, pp. 152-153) has shown that bacteria

resistant to penicillin and to streptomycin originate as genetic mutants. We have also worked out the patterns followed in the development of high-degree resistance to these two antibiotics. This year we studied the resistance patterns of aureomycin, chloromycetin, and neomycin in *E. coli*. The work on aureomycin was done by M. Demerec and Ethelyn Lively, and the rest by M. Demerec and Rada Demerec, who spent the summer of 1949 at this laboratory under a grant from the National Tuberculosis Association, administered by the Biological Laboratory.

Aureomycin. Results of the experiments indicate that high resistance cannot be obtained in one step, but may be built up in several steps. Because of its action on bacteria, this antibiotic was found unsuitable for detailed analysis of the resistance pattern. In addition to killing some of the bacteria, it suppresses division in the survivors. Since it loses some of its potency during an experiment, these suppressed bacteria begin to divide again when the concentration of aureomycin has decreased to a certain point. This behavior hinders the quantitative analysis of resistance.

Chloromycetin. The material used in experiments was obtained from Dr. John Ehrlich, of Parke, Davis & Company. This antibiotic becomes effective—that is, a detectable reduction in number of survivors is observed—at a concentration on agar plates of between 4 and 5 $\mu\text{g. per ml.}$ With further increase in concentration, the number of survivors drops rapidly, and at 13 $\mu\text{g. per ml.}$ no survivors are found. Strains isolated from survivors of the highest concentrations are more resistant than the original strain (first-step resistance). They begin to be affected at concentrations of between 10 and 13 $\mu\text{g.}$, and require up to 35 $\mu\text{g.}$ for complete elimination. Second-step resistant strains are very resistant. For them the effective concentration is between

30 and 50 $\mu\text{g.}$, and the lethal concentration about 100 $\mu\text{g.}$

Neomycin. The material for the experiments was obtained from Dr. Gladys L. Hobby, of Chas. Pfizer & Company. The bacteria are affected by concentrations of between 1 and 1.5 units per milliliter, and about 25 units are required to eliminate all of them. First-step resistant strains show a considerable degree of variability with respect to the concentrations needed to affect them. The observed range among 7 strains tested was from 4 to 15 units. The lethal concentration is between 25 and 35 units; that is, only slightly higher than the lethal concentration for the original strain. Second-step resistant strains, likewise, are only slightly more resistant than the first step resistant strains.

Cross-resistance tests. Tests were made to determine whether strains resistant to streptomycin are also resistant to chloromycetin and neomycin. All together, 42 strains were tested with each antibiotic. All tests were negative; that is, resistance to streptomycin did not affect sensitivity to the other two antibiotics.

General considerations. Since the development of resistant strains is an important factor affecting the clinical usefulness of antibiotics, information about resistance patterns is essential for effective use of these substances in medical treatment. Our earlier work showed that first-step strains resistant to penicillin are all very uniform and are only slightly more resistant than the original strain. Highly resistant strains can be obtained only in several steps, by always selecting the most resistant survivors for further propagation. Therefore it is relatively simple to prevent the development of highly resistant strains if the concentrations of penicillin used in treatment are sufficiently high to eliminate all the bacteria present.

The situation is quite different with

streptomycin. Here the variability among first-step resistant strains is very great, and some of them are completely resistant. Since high resistance may be attained in one step, the development of highly resistant strains cannot well be avoided.

The patterns of resistance to aureomycin and chloromycetin resemble that for penicillin. Therefore it may be expected that the clinical use of these two antibiotics will not be complicated by the development of resistant strains.

Neomycin, whose antibiotic activity closely resembles that of streptomycin, evokes a resistance pattern that is intermediate between those for penicillin and streptomycin. First-step resistant strains show a considerable degree of variability, and some of them have fairly high resistance. The development of highly resistant strains can be avoided only if a sufficiently high concentration can be used in treatment to eliminate all first-step mutants. For our strain of *coli*, this concentration is not lower than 25 units per milliliter. Since strains resistant to streptomycin are sensitive to neomycin, the use of a mixture of these two antibiotics would greatly lower the required concentration of each, provided chemical action of the compounds is not neutralized in mixtures.

PHENOTYPIC EXPRESSION OF DELAYED MUTANTS

During the past year an interesting genetic effect of yeast ribose nucleic acid was observed and investigated in *Escherichia coli* by Witkin and Jessie Flint. Cultures of strain B/r grown in broth containing 0.5 per cent sodium nucleate (Schwartz) were found to yield, on the average, significantly higher numbers of mutants resistant to bacteriophage T₁ than a series of control broth cultures. Tests made during the logarithmic growth phase showed

that the increase was not due to a heightened rate of mutation during the growth of the nucleate cultures. No difference in number of mutants between cultures grown with and without nucleate was observed until the "stationary" phase of the culture cycle was well under way. The average number of mutants rose continuously, in both broth controls and cultures containing nucleate, for about 72 hours, with the nucleate cultures maintaining a significantly higher average than the controls after the end of the logarithmic growth phase. A careful investigation of the effect of sodium nucleate on the growth rates of sensitive and resistant bacteria ruled out the possibility of differential stimulation of division in resistant mutants, or more active total division in the nucleate cultures.

Observation of individual nucleate cultures led to the formulation of the following hypothesis: that sodium nucleate increases the frequency of T₁-resistant mutants by hastening the phenotypic expression of spontaneous "delayed" mutants, which would ordinarily remain phenotypically sensitive until the occurrence of one or more divisions. This hypothesis was suggested primarily by the observation that large numbers of small-colony T₁-resistant variants occasionally appeared after 48 hours in a nucleate culture known to contain only the more common large-colony type of mutant at 24 hours. Since the small-colony T₁-resistant variant is relatively rare, it is very unlikely that any one culture will contain more than one clone of this type. The amount of division occurring between 24 and 48 hours of incubation is not sufficient to explain the new appearance of a large clone. Therefore, it seems likely that the clone of small-colony T₁-resistant variants must have been present at 24 hours in a phenotypically sensitive state.

A critical test of the hypothesis that sodium nucleate develops the phenotypic expression of delayed mutants is now under way. Ultraviolet-irradiated cultures, which are known to contain extremely large numbers of induced delayed T₁-resistant mutants, are being used in this investigation. Preliminary results indicate that sodium nucleate converts delayed mutants into "zero-point" mutants; in other words, that the ultraviolet-induced delayed mutants can be detected after treatment with sodium nucleate under conditions precluding division. In the absence of nucleate, division is required before the delayed mutants become phenotypically resistant.

Similar results have been obtained with high concentrations of casein hydrolysate. High concentrations of glucose and certain amino acid mixtures fail to duplicate the nucleate effect.

INHIBITION-REVERSAL TECHNIQUE

Sodium nucleate was used also by Witskin in the development of a new technique for investigating chemically induced bacterial mutations. The inhibitory action of a number of antibacterial compounds can be reversed by the addition of sodium nucleate. Among these are acriflavine and caffeine, which have been shown to be mutagenic (see Year Books Nos. 46 and 47), and various analogues of the naturally occurring purines and pyrimidines, which have not yet been tested for mutagenic activity. The method can be illustrated by describing its application to the study of mutations induced by acriflavine. Twenty-five tubes containing 5 ml. of 0.01 per cent acriflavine dissolved in nutrient broth are inoculated with 10^7 bacteria from a fresh broth culture of strain B/r. The tubes are incubated for 4 hours at 37° C., at which time the survival in each tube is about

10^{-8} . Sodium nucleate is added to each tube to give a final concentration of 0.5 per cent, and the tubes are incubated 18 to 24 hours. The bacteria not yet killed by the acriflavine at the time of addition of nucleate are able to divide at the normal rate to give cultures of full titer after incubation. Each culture is assayed to determine the number of bacteria per milliliter and the number of T1-resistant mutants per 10^8 bacteria. The frequency distribution of mutants in the nucleate-reversed series of cultures is plotted and compared with the frequency distribution of mutants in a similar series of control cultures. The control cultures are inoculated with the same number of bacteria found to be viable in the acriflavine series at the time of addition of nucleate, and are grown in the presence of 0.5 per cent sodium nucleate without exposure to acriflavine. The distribution of mutants in the control series is extremely constant, with most of the cultures in the range from 10 to 50 mutants per 10^8 bacteria. In the acriflavine-nucleate series, most of the cultures have over 200 mutants per 10^8 bacteria at the end of growth. Experiments with artificial mixtures of sensitive and resistant bacteria have indicated that selection is not responsible for the effect.

Both zero-point and delayed mutations are detected by this technique, as both types of induced mutations contribute to the final crop of mutants in the experimental cultures. The method has other advantages over those used previously: (1) The nucleate reversal effectively removes the acriflavine from further activity, more completely than several centrifugations and washings. (2) Selection due to differential survival of resistant mutants initially present in the treated population can be ruled out directly, by using inocula small enough to contain no "background" mutants. (3) Statistical error in the estimation of muta-

genic potency is considerably less than with methods in which the observation of small numbers of mutant colonies is the basis of calculation.

The inhibition-reversal method, as illustrated by the acriflavine-nucleate system, is applicable to a great many other similarly reversible systems, some of which are already under investigation.

EXPERIMENTS WITH *DROSOPHILA*

During the past year a great deal of work has been done in continuation of the study of mutagenic action of chemicals on the sperm of *Drosophila*. This research has been carried on by Wallace, assisted by Leona Hahn, Helen Spring, Mrs. Jennie Buchanan, and Raymond Millemann. If one examines the data gathered throughout the years this program has been pursued, one finds that they indicate several fairly distinct periods: (1) During the initial period the aerosol technique was being tested with miscellaneous dyes and organic salts. The results of these experiments were uniformly negative (Year Book No. 45, pp. 156-157). (2) A second period started with the first test of the carcinogenic substance dibenzanthracene. During this period the results indicated that certain chemicals were mutagenic; chromosomal aberrations were induced by these chemicals, and the results of different experiments using the same chemical were fairly consistent (Year Book No. 46, pp. 127-131). (3) The third period was a short, not too distinct, time during which the variability from experiment to experiment became alarming and only occasionally was it possible to obtain confirmation of previous experiments (Year Book No. 47, p. 170). (4) The fourth period, encompassing all of the past year, has been characterized by uniformly negative results except in those experiments us-

ing nitrogen mustard, methyl-*bis*(beta-chloroethyl)amine hydrochloride. A summary of the experiments made during this period is presented here (table 1), but a fuller analysis will be published elsewhere.

Testing the data given in table 1 for homogeneity by the Brandt and Snedecor method of computing chi square gives the

ments, we obtain a chi square of 1307 with 19 degrees of freedom; the probability of getting such a chi square from a homogeneous population is negligible, and it can be concluded that nitrogen mustard does induce mutations.

The study of lethals included analysis not only of their frequency, but also of

TABLE 1

SUMMARY OF THE FREQUENCY OF LETHALS OBTAINED DURING 1948-1949 BY TREATMENT OF *DROSOPHILA* MALES WITH VARIOUS CHEMICALS

Treatment	No sperm tested	No lethals	% lethals
Control	39,928	122	0 306
1,2,5,6-dibenzanthracene	60,758	186	0 306
<i>p</i> -hydroxyazobenzene	7,178	19	0 265
beta-naphthylamine	1,980	5	0 253
azoxybenzene	773	1	0 129
azobenzene	1,907	2	0 105
<i>p</i> -dimethylaminoazobenzene	2,674	7	0 262
3,4-benzpyrene	1,499	4	0 267
1,2-benzanthracene	1,185	1	0 084
methylcholanthrene	3,003	9	0 300
acetylaminofluorene	1,172	2	0 171
pyrene	1,146	2	0 175
anthracene	920	4	0 435
alpha-naphthylamine	1,296	6	0 463
phenanthrene	1,044	7	0 670
<i>p</i> -aminoazobenzene	741	2	0 270
<i>p</i> -diethylaminoazobenzene	859	2	0 233
acridine	873	2	0 229
sodium desoxycholate	1,713	5	0 292
Subtotal	130,649	388	0 297
nitrogen mustard	3,757	153	4 07
Total	134,406	541	0 403

following results: If nitrogen mustard results are omitted, the chi square for 18 degrees of freedom is 14.06; the probability of obtaining a chi square as large as this from a homogeneous population is 0.74. There is no reason, then, to conclude from these experiments that any one of these chemicals differs from any other, or from the control, in its mutagenic properties. If we include the nitrogen mustard experi-

ments, Of the 388 lethal gene mutations obtained in experiments other than the nitrogen mustard experiments, 372 were located in one or another of the five regions of the X chromosome formed by the mutant genes *ec*, *ct*, *v*, and *g*. No evidence was found that any of these 372 lethals was involved in a chromosomal rearrangement. It should be emphasized that 114 lethals arising spontaneously in

the control experiments were among those tested for position and for the presence of concurrent chromosomal rearrangements. The confidence interval, then, for the frequency of chromosomal rearrangements occurring with spontaneous lethal gene mutations is 0 to 0.03. (This interval is calculated by use of the equation $1-p = \text{antilog}\left(\frac{\log a}{n}\right)$, where p is the upper limit of the confidence interval, a is the level of significance, 0.05, and n is the number of observations, 114.) If we turn now, for example, to experiment 185 (one of the experiments using *p*-hydroxyazobenzene made during 1947), in which 3 aberrations were found among 35 lethal gene mutations, we can calculate the probability that these were spontaneous gene mutations occurring concomitantly with aberrations. Using the 0.03 upper limit and fitting the normal curve to the binomial with Yates' correction for small figures, it is found that the probability of getting 3 aberrations with 35 lethal mutations is 0.0375. Since this figure is obtained by use of the upper limit, we conclude that some factor other than chance was operating in experiment 185 and that the aberrations observed were not of spontaneous origin.

In conclusion, it may be mentioned that the following factors have been considered in an effort to locate the source of variability in our experiments: genetic constitution of the treated flies, solvents, temperature, nebulizers, length of treatment, killing of treated flies, size of treated flies, condition of chitin, rate of respiration (as controlled by CO_2), and condition of the M-5 tester chromosome as determined by cytological and genetical analysis.

An analysis of the relation between dominant and recessive lethals induced by nitrogen mustard has been undertaken during the past year. The purpose of this

analysis was to obtain data bearing on the theory that dominant lethals are the result of inviable chromosomal rearrangements. The arguments presented by Muller and by Lea (D. E. Lea, *Actions of radiations on living cells*, 1947) are convincing but are based on differential genetic effects of varying X-ray treatment. Since nitrogen mustard induces both gene mutations and chromosomal rearrangements, but in a ratio different from that induced by X-rays (Auerbach and Robson, *Proc. Roy. Soc. Edinburgh* (B), vol. 62, pp. 271-283, 1947), it seemed that dominant-lethal data from nitrogen mustard experiments would be enlightening.

In contrast with X-rays, whose dosage can be measured and controlled accurately, nitrogen mustard, as applied to flies by the aerosol technique, gives variable results. Because of this, it was decided that the ratio of dominant to recessive lethals in a number of experiments should be obtained and compared with similar data obtained for various doses of X-rays.

The dominant-recessive relation for nitrogen mustard (25 separate experiments) was found to be nearly identical with that expected for X-rays. Since viable rearrangements are less frequent with nitrogen mustard than with X-rays, but dominant lethals for the two are equal, it seems profitable to investigate this problem further. The observed difference may be caused either by a greater induction of primary breaks by X-rays or by the greater opportunity for restitution in the nitrogen mustard experiments.

A third series of experiments, involving X-radiation, was initiated by our group and is now being pursued at the Biological Laboratory of the Long Island Biological Association. It was necessary to know whether eggs and larvae can survive a chronic treatment of 133 ± 1 units per day,

and whether, if they do survive, an appreciable number of lethal gene mutations can be found in the adult flies.

The eggs of a large number of Oregon-R parents were collected daily for 5 days. Those collected on the first day were irradiated daily for 5 days from the day of collection, those collected on the second day were irradiated for 10 days from the day of collection, those of the third day for 15 days, the fourth for 20 days, and the fifth for 25 days. These treatments covered, respectively, the periods egg to larva, egg to pupa, egg to 5-day-old adult, egg to 10-day-old adult, and egg to 15-day-

old adult. The data obtained are given in table 2, combined with tentative data of a confirmatory experiment carried out at the Biological Laboratory.

The proportion of lethals recovered in the sperm of adult males increases linearly with time until the fifteenth or twentieth day, when it becomes stabilized. This agrees with the work of others (see Demerec and Kaufmann, *Amer. Naturalist*, vol. 75, pp. 366-379, 1941), who have found that sex-linked lethal gene mutations and dominant lethals are eliminated from sperm about 14 to 17 days after treatment of male *Drosophila* with X-rays.

TABLE 2

FREQUENCY OF SEX-LINKED LETHALS OBTAINED BY IRRADIATION OF GROUPS OF FLIES FOR VARYING NUMBERS OF DAYS

Treatment Days	r units	No. sperm tested	% lethals \pm S.E.		Expected*
0	0	2107	0.190 \pm 0.095		.
5	539	2564	1 21	0 216	1.44
10	1093	1102	3 99	0 590	3.26
15	1617	2454	4.60	0 423	4.32
20	2156	1336	6.14	0 657	5.76
25	2695	327	5 20	1.23	.

* Expected on the basis of a linear increase for 20 days.

CYTOLOGY OF BACTERIA

BERTHE DELAPORTE

To ascertain, if possible, whether the nuclear element seen in all bacterial cells is haploid, diploid, or polyploid—that is, whether it is a single nuclear unit or is composed, at least at certain times during the growth of a bacterial culture, of several fused nuclear units—studies have been made of the bacterial nuclear element under many different conditions of observation, and also in cells treated with radiations or chemical mutagens, during lysis by bacteriophage, and in different strains grown under various conditions.

The technique used most often was staining with Giemsa after fixation with osmium tetroxide vapor and hydrolysis with *N* HCl at 60° C. for 10 minutes. Post-fixation with alcoholic sublimate after the osmium tetroxide treatment gave identical results. Fixation of cells on the agar block before making an impression of the culture gave the same results as fixation after impression, provided the bacteria were not allowed to dry before fixation.

Permanent mounting medium. Since no good technique of mounting was known

that would allow preservation of Giemsa-stained preparations for a few months, several procedures were tried, and Abopon, a water-soluble resin used by E. Lieb to mount amyloid-stained preparations, was found to be convenient and satisfactory. Eight months after mounting, the preparations are the same as on the first day. Staining with Giemsa and with Feulgen gives the same results, but with Feulgen the nuclear element is smaller than with Giemsa.

INFLUENCE OF CULTURE CONDITIONS ON STRUCTURE

Bacteria of the same strain of *Escherichia coli* (B/r/1, for example), grown in different aerated liquid media (broth or the GR medium of Doermann) and subcultured in one or the other medium, show, at the same age, differences in length of cells and in shape of the nuclear element. Culture for 24 hours in broth followed by 105-minute subculture in broth results in very short cells, sometimes almost spherical, with large round or ovoid nuclear elements. Culture for 24 hours in GR medium followed by 105-minute subculture in broth produces medium-length cells with globular nuclear elements. Culture for 24 hours in GR and 105-minute subculture in GR produces long cells in which the nuclear element often appears as an axial rod.

When *E. coli* (B/r) is grown in non-aerated broth, it produces, in a $4\frac{3}{4}$ -hour culture, medium or long rods with 4 to 8 nuclear elements, isolated but close together, so that they appear as transverse rods (perpendicular to the long axis of the cell), which divide lengthwise and therefore often are seen as V or U shapes.

INFLUENCE OF ULTRAVIOLET RADIATION

When cells of *E. coli* are irradiated, they form "snakes." B-strain cells, irradiated

during the exponential phase of growth, produce snakes in which the nuclear element is seen, most frequently, as a line of adjacent granules along the axis of the filament, or else as an axial line showing no distinct granules. Sometimes the granules are separated, isolated or two by two. The ends of snakes contain no nuclear substance.

ACTION OF BACTERIOPHAGE

When a suspension of bacteriophage is added to a sensitive strain in exponential growth in GR medium (T₄ to strain B/r/1, for example), no change is evident for the first 10 minutes, except that in some cells a few granules are visible at the periphery, but after 20 minutes most of the cells are completely and uniformly filled with chromatic substance. (A few cells, resistant to infection, will maintain a normal aspect throughout the process.) One to four small chromatic granules are seen at the surface of some cells. After 25 minutes the membrane has lost its rigidity and sharpness, and small knobs are visible on the cells. After 30 minutes this effect is accentuated. After 38 minutes lysis begins; the cell expands considerably, taking the shape of a racket with a short handle or of a complete sphere in which the whole interior is uniformly chromatic, and then bursts, losing all its chromatic substance. Around newly lysed cells it is possible to see a large number of small points, stained with Giemsa. It is difficult to determine whether or not these are phages, or aggregates of phages, just leaving the cell. These phenomena have also been observed with the phase-contrast microscope. The infected cells remain dark during the entire time of infection and internal multiplication of the phage, and then are seen to swell rapidly into round bodies, which burst a few seconds later and immediately become transparent,

with a remnant of membrane visible as a ghost.

When phage is added to a culture of *E. coli* containing snakes induced by ultraviolet radiation, large, round swellings are observed in the snakes—one or two in short snakes, several in long ones. With the phase-contrast microscope, a few minutes after the beginning of the experiment, one sees transparent spaces, approximately square and occupying the whole width of the snake, like complete interruptions of its living substance. A few minutes later, these spaces swell rapidly into round, transparent bodies, sometimes 15 to 20 microns in diameter, sometimes larger. Occasionally smaller round bodies appear on the sides of snakes, but these are filled with protoplasm like the interior. Sometimes the large bodies are in the form of spindles. Staining shows granules of nuclear substance at the periphery of the large bodies. In the remainder of the snakes, the chromatin is in shapeless masses. Some snakes look like a string of beads, which are sometimes closely joined together in an irregular line, but more often separated by short threads of chromatic substance. About 35 minutes after infection, many snakes consist of lengthened masses of chromatic substance, two or three times the normal diameter of cells, separated by thinner, threadlike sections, which are sometimes very long. In living preparations, sometimes one of the large bodies bursts, leaving only debris in its place. In both stained and living preparations, some of the snakes are ghostlike, of normal or smaller diameter, with a few chromatic granules at the periphery.

Lysis by bacteriophage was also observed on a strain of *Bacillus cereus*. Ten minutes after addition of the phage, the nuclear elements of the cell fuse and 10 minutes later the whole cell interior is filled with a chromatic, homogeneous substance. At 60

minutes the cell is considerably larger in volume, the contents always homogeneous and the membrane neatly outlined. At lysis, the chromatic substance recedes from the periphery, in deeper and deeper scallops, until first only an axial rod is left, then only a few granules, which finally disappear, leaving the cell with no chromatic substance. The bacterial membrane keeps its cylindrical shape throughout the process; but the cells, which at first are in long chains, later become isolated. The above-described process occurs simultaneously in all cells of a culture.

ACTION OF STREPTOMYCIN

Antibiotics, when added to a culture, bring about changes in cell form. Penicillin, for example, induces the formation of round bodies on the cell. In certain mutant strains, the cell shape is modified only when cultures are grown on normal medium containing no antibiotic. For example, the streptomycin-dependent strain B/r/Sd, which has normal cell structure when cultured on streptomycin-agar, grows very slowly and forms "snakes" on medium lacking streptomycin. The cells first become elongated, with the nuclear substance in the shape of an axial rod, then gradually develop into long snakes. These are filled with nuclear substance, continuously or in fragments, with occasional swellings or enlargements in which the nuclear substance appears as either contiguous granules, an axial thread, or a loose net of granular filaments.

INACTIVATION BY ULTRAVIOLET AND RECOVERY BY LIGHT

Exposure of a culture of *E. coli* to an appropriate dose of ultraviolet rays causes death of 99 per cent of the cells. These cells do not at once show changes in their structure, except for the appearance of a

few small granules of chromatic substance—perhaps detached from the central mass of nuclear substance—at the periphery of some cells, most often near a pole. Observations were made on strains B and B/r. After about an hour of culture in the dark in aerated broth or agar, the dead cells appear to be smaller, and their chromatin is diffused uniformly throughout (or almost throughout) the cell so that it is more or less completely mixed with the cytoplasm. This effect persists for a number of hours before destruction of the cell is complete. The few cells that do not die maintain their normal structure and begin to multiply normally after a longer than usual lag phase. Later, in B/r (in aerated broth or M-9), some snakes are formed; these have isolated nuclear granules either in an axial line, scattered, or grouped near the middle of the snake. The cells that remain short have only one central granule, or two when they are dividing. In strain B, on agar, almost all the surviving cells form snakes, which lengthen gradually, the chromatin filling the whole interior or being more or less diffuse but localized in the middle part of the snakes. Then the chromatin separates from the cytoplasm, and takes the shape first of reticular structures, which appear as if made up of tiny mixed chromatinic threads, then of separate rectangular fragments having this reticular structure, and finally of granules, more or less closely related, arranged in squares or rectangles. At this stage new cells appear in the culture. They are large and isolated, having a sky-blue cytoplasm and two nuclear elements in the form just described, like the cells of certain young cultures. These isolated cells are found in increasing numbers in aging cultures, and there is a parallel decrease in the number of snakes.

If such ultraviolet-treated cultures are strongly illuminated for about an hour,

soon after irradiation, and then subcultured, a high percentage of the cells recovers (A. Kelner, *Proc. Nat. Acad. Sci.*, vol. 35, pp. 73-79, 1949). In strain B/r, after this light treatment followed by 2-hour culture in the dark in aerated broth, a great many cells begin to form snakes, in which the nuclear substance very often appears as contiguous granules, placed in an axial line. As the snakes lengthen, the nuclear granules are either in an axial line or scattered; exceptionally, they are in two parallel rows. Very few of the cells have the appearance of the dead cells, filled with diffuse chromatin, commonly seen in the same culture without light treatment. Strain B on agar, given similar treatment, shows a few dead cells with diffuse chromatin, a very few small cells with central, more or less globular nuclear elements, and a large number of snakes, which lengthen progressively, and which have the same nuclear structure as the snakes that form in the absence of light treatment. Later, isolated cells are seen.

OBSERVATIONS ON BACILLI

Formation and germination of spores, and first cellular divisions in a new culture, were observed in *Bacillus myroides*, *B. cereus*, *B. megatherium*, and *B. macerans*. In *B. cereus*, at the beginning of sporulation (16- to 24-hour culture), the nuclear substance, in almost all cells, appears in the form of several scattered granules. The number and placement of these granules are not constant; perhaps they are linked together, but if so their ties are not visible with the methods used. The one situated nearest an end of the cell becomes the nucleus of the spore. It gradually enlarges, stretching into a short rod; at the same time a homogeneous and dense cytoplasm, stained pink with Giemsa, forms around it and finally takes the ovoid shape and the

dimensions of a mature spore. The cytoplasm then changes its staining characteristics and stains sky blue; the spore is enclosed in a refractive membrane; and the nuclear element moves to the periphery, taking the shape of a short curved rod (in side view) or ovoid ring (front view), or of two or three closely related granules. During this process, the cytoplasm, nuclear substance, and lipid globules that were in the sporangium outside the spore gradually disappear—perhaps assimilated by the spore in formation. The spore is then liberated. In certain species (*B. mycoides*, for example) spores remain permanently inside a remnant of sporangium membrane, which shrinks so that only two short finger-like appendages are seen at the poles of the spore.

During germination, the spore becomes larger, and the nuclear element moves in from the periphery to the center, assuming the shape of a wavy filament or of several closely related granules, which often divide into two symmetrical parts before the

young cell emerges from the spore coat. A second, and sometimes a third, nuclear division often occurs before the formation of a visible transverse membrane inside the rod. A small granule of nuclear substance, which stains Feulgen-positive, is sometimes seen discarded on the empty spore coat; probably it is a remnant of the nuclear substance of the sporangium.

During the first divisions in a new culture of *Bacillus*, the rate of nuclear division is more rapid than the formation of transverse membranes and lengthening of the cell, so that very short cells are formed. Often their width is greater than their length, and consequently the nuclear element is in the form of transverse rods, unless deformed by near-by elements. These transverse rods divide lengthwise, often assuming V or U shapes, and the halves are pulled apart in the direction of the long axis of the cell, as happens in all bacterial divisions. The nuclear element is rarely seen in the shape of an axial thread during the early divisions.

INTRACELLULAR GROWTH AND GENETICS OF BACTERIOPHAGE

A. H. DOERMANN AND CAROLYN F. R. DISSOWAY

The biosynthesis of virus particles presents to the investigator a challenging, but extremely complicated, problem. Nevertheless, significant advances have been made in the past few years, especially where bacteriophage has been used as the experimental organism. The finding that genetic recombination is a predictable phenomenon, which occurs when related phage particles are growing in the same bacterial cell (Hershey and Rotman, *Genetics*, vol. 34, p. 44), is perhaps the most notable achievement so far. Not only is the result of fundamental interest in itself, but it also affords to phage-synthesis studies a specificity that is possible only by ap-

plication of the sensitivity of genetic identification.

The approach to the problem of bacteriophage growth that we are trying to develop is one which will make possible the combined application of a genetic and biochemical attack. With this plan in mind, two methods were developed whereby bacteriophage-infected cells of *Escherichia coli* can be disrupted and made to liberate their phage contents at any time during the phage life cycle (see Year Book No. 47, 1947-1948). These methods have been extended and utilized in several ways during the past year. The cyanide-lysis technique has been modified in such a way

that it can now be used to study the phage contents of single bacterial cells at any stage of the reproductive cycle. This modification and the original method have been applied to the study of genetic recombination, with the hope of finding some clue to the mechanism involved.

In addition, another problem has been encountered, which at first sight does not seem related to the plan of investigation mentioned above, but which is nevertheless expected to show a connection with it after fuller study. A genetically unstable phage type has been isolated and preliminary experiments have been made in a study of the mutability pattern of the phages derived from this stock.

TIME OF OCCURRENCE OF GENETIC RECOMBINATION

Hershey and Rotman have shown that when bacteria are mixedly infected with several T2 particles of the types rh^+ and $r'h$, the progeny from single bacteria contain all four combinations of these factors, viz., rh^+ , $r'h$, rh , and $r'h^+$. Their studies of about twenty independently arising r types have shown that they fall into three categories with respect to amount of recombination with the h locus. With one type there is about 2 per cent recombination. Two others yield approximately 35 per cent recombination. With a third, larger, group, about 15 per cent recombination is found. Our first question concerned the stage of phage growth at which genetic recombination takes place. It seemed likely that recombination might occur only late in the latent period, when the infected bacterium contains numerous new phage particles. Such a result would suggest that recombination takes place between the newly formed phage particles. It appeared possible, however, that the first newly formed phage particles might

already be recombinants, which would suggest that mixing of genetic material must take place even before the presence of phage particles can be demonstrated.

The experiments to test these alternatives were made with mass cultures of stocks received from Hershey. They were carried out in the manner described by Hershey and Rotman, except for incidental technical changes. The phages selected for crossing were $T_2Hr_{13}h^+$ and $T_2Hr'h$, for which Hershey and Rotman found about 2 per cent recombination. Bacteria that had been mixedly infected with these phages were subjected to the cyanide-lysis procedure at intervals after infection. Platings were made from the lysed aliquots against mixed indicator strains that permit identification of all four types of phage expected to result from this cross. The results of experiments indicate that, at a time when there are only 2.3 completed phage particles per bacterium, there is already as high a proportion of recombinants as later. It is therefore clear that recombinants occur with about the same probability among the first-formed phage particles as among those formed later in the latent period, indicating that genetic mixing takes place before the completion of any of the phage particles.

DISRUPTION OF SINGLE BACTERIA BY CYANIDE

To make a detailed genetic analysis, it is often important to observe the progeny of single crosses separately. Similarly, in studying the growth and genetics of bacteriophage it is essential in many cases to have data on the progeny from single bacteria. The next problem attacked, therefore, was that of devising a technique whereby single cells might be disrupted and thereby induced to liberate their phage contents. The method finally used is pat-

turned after the original technique of Burnet (*Brit. Jour. Exper. Pathol.*, vol. 10, p. 109, 1929), as modified by Delbrück. It is similar to the cyanide-lysis procedure except for the following details: The medium used is broth made according to Hershey and Rotman. Infected bacteria are distributed by drops to individual tubes, each tube having a probability of about 0.25 of receiving one infected cell. At a designated time the tubes are chilled and cyanide is added. After lysis has been induced, the entire individual samples are plated against mixed indicator strains.

In these experiments, T2Hr₁₃ and T2Hh were again used in mixed multiple infection. The results will first be analyzed on the basis of total yield of phage per cell, and then on a genetic basis. Only those bursts that contained more than one infective center were included in the analysis. Those containing a single particle were omitted for several reasons. Some of them were undoubtedly due to unadsorbed particles of the infecting phage population which escaped antiserum inactivation. Those stemming from infected bacteria fell into two groups, namely, those actually containing a mature phage particle at the time of addition of cyanide, and those not containing one. T6 was omitted from these experiments for technical reasons, and the bacteria lacking a mature phage particle would not be lysed by the cyanide alone. They would thus make a plaque on the plate, because the cell would recover from the cyanide there, resume synthesis of phage, and lyse. To omit the single plaques from the Poisson analysis seemed justified inasmuch as they would not materially affect the estimation or the distribution of the other bursts.

Five experiments were made, and 139 of 538 tubes were found to contain more than one phage particle. By totaling the Poisson analyses of the individual experi-

ments it was found that theoretically 119 of these were single bursts, 18 were double bursts, and 2 were triples. The data indicate a bimodal distribution, corresponding roughly to the bursts from single bacteria and from the accidental doubles. In a general way, it may be said that there is great variability in the amount of intracellular phage growth accomplished in the individual bacteria at a given time. Since the adsorption period was only 2 minutes, and since approximately 10 phage particles were adsorbed in that time, the difference among individual bacteria cannot be ascribed to a difference in the time of infection alone.

These results agree fairly well with those obtained by Delbrück with the virus T1 (*Jour. Bacteriol.*, vol. 50, p. 131, 1945) when he studied the phage yields from individual bacteria allowed to lyse normally. A more appropriate comparison can be made with Hershey and Rotman's results from crosses with T2H. The histogram of 100 of their single bursts lysing normally shows a distribution more concentrated around the mean. Our results show a considerably wider distribution in the relative sizes of yields from individual bacteria, with a concentration of bursts less than the mean. This difference can be explained on the hypothesis that phage growth proceeds linearly in individual bacteria, but that there is a spread in the time at which the first mature phage particles appear in the individual bacteria. If the growth of phage in our bacteria were allowed to proceed up to the time of normal lysis, both the mean and the individual yields would be moved along the abscissa, resulting in a more concentrated distribution of the bursts. This hypothesis would also predict that a curve describing intracellular phage growth in mass cultures should bend upward during the first portion of the rise, since one would add linear rates from in-

dividual bacteria starting at different times. This is precisely what was observed in the earlier experiments (see Year Book No. 47).

The results of these single-burst experiments add detail to the picture of intracellular phage growth suggested by the mass-culture experiments. It is now clear that the phage obtained in the mass-culture experiments is not derived from a small number of easily disrupted bacteria, but from approximately 100 per cent of the infected cells.

CORRELATION IN THE OCCURRENCE OF ALTERNATE RECOMBINANT TYPES

The single-burst data already described were also studied in an attempt to determine whether the occurrence of one recombinant is correlated with the occurrence of the alternate type. Hershey and Rotman studied crosses between representatives of the three groups of *r* mutants and the *h* mutant. Only in the crosses involving *h* and *r*₇, where about 15 per cent of the progeny were recombinants, was a significant positive correlation found. It appeared surprising that no correlation could be detected between *h* and the more closely linked *r*₁₃, where only 2 per cent recombination was found. It seemed possible that an early correlation might have been obliterated by growth of either recombinant during the latent period. Our experiment could shed some light on this explanation, and the progeny of the single bursts were therefore grouped in four genetic classes, *rh*⁺, *r*⁺*h*, *rh*, and *r*⁺*h*⁺. Of the 139 samples plotted, the classification of plaques was not dependable in 19 cases, and 12 other bursts contained only one of the parental types. These cases were therefore excluded from the analysis. The remainder were classified, and fell into the grouping shown in table 3. The amount of correlation may

be estimated in two ways. First, the correlated absence of recombinants may be studied. From the table it is seen that 77 of the total of 108 bursts lacked the *r*⁺*h*⁺ recombinant, whereas 65 lacked *rh*. The number expected to lack both simultaneously, on a random basis, is the product of the above ratios, which is 0.43. This predicts that 46 bursts should show neither

TABLE 3
SINGLE BURSTS FROM CROSS T₂Hr₁₃ × T₂Hh.
DESIGNED TO TEST CORRELATION IN THE
OCCURRENCE OF ALTERNATE
RECOMBINANT TYPES

Type	Frequency	Type	Frequency
0 <i>rh</i> : 0 ++	53	3 <i>rh</i> : 1 ++	1
		2 <i>rh</i> : 2 ++	1
1 <i>rh</i> : 0 ++	12	1 <i>rh</i> : 3 ++	2
0 <i>rh</i> : 1 ++	9		
		3 <i>rh</i> : 2 ++	1
2 <i>rh</i> : 0 ++	10	2 <i>rh</i> : 3 ++	1
1 <i>rh</i> : 1 ++	7		
0 <i>rh</i> : 2 ++	2	4 <i>rh</i> : 2 ++	1
		3 <i>rh</i> : 3 ++	1
3 <i>rh</i> : 0 ++	~	2 <i>rh</i> : 4 ++	1
2 <i>rh</i> : 1 ++	1		
1 <i>rh</i> : 2 ++	1	6 <i>rh</i> : 1 ++	1
0 <i>rh</i> : 3 ++	1		

Total recombinants are 75 *rh* : 50 ++

recombinant. The number found, which was 53, is higher, but not significantly so. The result indicates that the presence or absence of one recombinant type is independent of the presence or absence of the alternate type.

On the other hand, the correlation coefficient, r_{xy} , between *rh* and *r*⁺*h*⁺ may be calculated. Hershey and Rotman have already shown that a correlation exists between the size of individuals and the number of recombinants in them. For this reason the coefficient of correlation must be calculated using the numbers of recombi-

nants as fractions of the individual burst sizes. When r_{xy} is calculated in this way, no correlation can be detected. The conclusion is that a reciprocal exchange in the later stages in the development of the virus particle is highly improbable. It is nevertheless possible that a reciprocal exchange occurs earlier, and that the correlation is effaced by subsequent reactions which complete the phage particles at random.

From Hershey and Rotman's genetic experiment taken together with the present results, we can draw one conclusion: that phage particles do not reproduce by division as unicellular organisms do. This conclusion is reached as follows. We now know that the first completed phage particles in mass cultures have about the same probability of being recombinants as the particles found later. If division is the mechanism of phage reproduction, recombinants should develop into large clones in those single bursts where they occur early, since an early recombinant should grow into more through subsequent divisions. Clones, however, were not observed by Hershey and Rotman, nor have they been seen in these experiments. The recombinants in Hershey and Rotman's experiments were distributed at random among the bursts.

In agreement with this conclusion is the fact that it is not possible to recover active phage from the infected bacteria during the early part of the latent period. Even the infecting phage particles can no longer form plaques if the cell is disrupted during the first third of the latent period. If reproduction of phage is by simple division, at least one phage particle should be available at all times during the latent period.

A GENETICALLY UNSTABLE SERIES OF PHAGE TYPES

The standard procedure for making bacteriophage stocks with a relatively low

frequency of mutant types is to infect a bacterial culture from a plaque that has arisen from a single phage particle. The lysate obtained in this manner is generally pure, except for a small number of mutant types that invariably arise in handling numbers of this order of magnitude. This procedure was applied to a peculiar scalloped plaque that appeared in an experiment where T4r was used. The resulting lysate was not pure, however, but contained less than 90 per cent of the plaque type that was sought, the remainder being a mixture of other types. The procedure was repeated several times with the same result. Serial plaque isolations were also made, with no better success. It appeared that a mutable phage type was under observation, and on this hypothesis the situation was investigated further.

The first problem was one of identification and differentiation of the several plaque types arising in the plating from a scalloped plaque. The technique used was to suspend an entire plaque in broth, dilute appropriately, and then plate by the agar-layer method. Platings were made of seven apparently different plaques coming from the phage population of a single scalloped plaque. Of these, five proved to be differentiable on the medium used. The other two were probably examples of one of these types. Those differentiable were numbers 1, 2, 5, 6, and 7. They are described in table 4. Stocks were made by infecting bacterial cultures from plaques of these five types.

To verify the fact that these strains were T4 mutants, host-range experiments were made. Bacteria resistant to standard T4 were also resistant to these types, and T4-sensitive bacteria were sensitive to them. To obtain more critical evidence, stocks of types nos. 6 and 7 were compared serologically with the original T4r. They were found to be qualitatively and quantitatively identical with T4.

The composition of the phage populations in plaques of the various types was investigated to learn something about the pattern of mutability among the types of this group. This was done by assay of plaques of the various types described in table 4, followed by classification of at least 100 plaques from each population. The results are summarized in the last column of table 4. From these it can be seen that all five types are different with respect to the populations of their plaques. Type

That this is, in fact, an important consideration will be clear from subsequent data.

During one-step growth studies, differences in rate of adsorption were noted among these T₄ types. To study this in a more precise way, a further experiment was made. It is known from the experiments of T. F. Anderson (*Jour. Bacteriol.*, vol. 55, pp. 637, 651, 659) and of M. Delbrück (*Jour. Bacteriol.*, vol. 56, p. 1) that the adsorption of certain strains of T₄ is

TABLE 4
CHARACTERISTICS OF THE T₄ UNSTABLE SERIES OF PHAGES

Type no.	Approximate plaque diameter (mm)*	Appearance of plaque	Cofactor requirement†	24 hour plaque contents‡
1	2-3	Clear halo	None, indole-sensitive	Nos. 1, 2, (5)
2	3-5	Turbid halo	Broth constituent, indole-sensitive	Nos. 2, (5, 7)
5	3-5	Turbid, speckled halo	Not tested	Nos. 1, 2, 5, 7, (6)
6	3-4	Turbid, scalloped halo	Broth or hydr. casein constituent, indole-sensitive	Nos. 1, 2, 5, 6, 7
7	1-1.5	Very narrow halo	Calcium, indole-resistant	Nos. 1, 2, 5, 7

* Absolute values depend on plating conditions and therefore vary considerably from plate to plate. The relative plaque sizes are nevertheless quite dependable.

† Based on preliminary data only.

‡ Parentheses indicate that these types occurred rarely in the plaque assayed.

no. 2 is relatively stable, in the sense that its plaques contain few phage particles of the other types. No. 1, on the other hand, is unstable, since its plaques invariably contained type no. 2 in addition to type no. 1. The other three types are even less stable than no. 1, since their plaques contain phage particles of several other types. If the comparison were based on the percentage of mutants present, the order of stability would be slightly altered. It should be noted, however, that these data may not reflect relative mutational instability, but rather may indicate differences in relative selective advantage of the various types during growth of the plaque.

markedly influenced by the presence of tryptophane, indole, and calcium. To discover whether the adsorption cofactor problem had any bearing on the present case, a preliminary test was made to see whether cofactors influenced adsorption here. A mixture of two of our T₄ types was added to a large excess of bacteria in the presence or absence of the substances to be tested. Measurements were made of the percentages of each of the phage types that were adsorbed. Although the results are insufficient at this time to draw any specific conclusions about the cofactor sensitivity of the various types, it is clear that some of the substances tested do influence

the rates of adsorption of the different phages to different degrees.

All plaque analyses described so far were carried out on plaques incubated 20 to 24 hours at 37° C. In the light of information about the effect of adsorption cofactors, it seemed desirable also to study the younger plaques, where the cofactor condition of the plates had not been subjected to so much metabolic alteration. Plaques of T4 are first visible after 3½ to 4 hours' incubation at 37° C. The youngest plaques that can be analyzed, therefore, are 4-hour plaques. The most significant factor in the results is that in all cases the 4-hour plaques contained only an insignificant proportion of mutants as compared with corresponding older plaques. It is furthermore significant that in the assays made on type no. 6 plaques of various ages, the percentage of mutant types is correlated with the age of the plaque. The results seem clearly to indicate that the great variety of phage types in the 20- to 24-hour plaques is in large part due to a selective mechanism operating during the growth of the plaque. Since the titer of the plaque from 8 hours to 20–24 hours increases only three- to fourfold, whereas the percentage of mutants increases more than thirty fold in comparable cases, the actual survival or the selective growth of the mutants must play an important role in their relative accumulation.

One technically useful result of these experiments is that it is now possible to prepare stocks of the various types with a

relatively high degree of purity, by infecting a bacterial culture with a 4-hour plaque rather than with an older one. In this way stocks of no. 6 with less than 0.2 per cent mutants have been prepared. It is hoped that these types will now become useful genetic markers for more advanced experiments.

Before the effect of selection among these phage types was discovered, the great variety of types arising from one phage particle in a single plaque seemed best explained by extreme mutability at certain genetic sites in the phage particle. To discover whether the observed mutability is due to instability in specific loci, or whether the hereditary material of these phages is generally unstable, tests were conducted to see whether hereditary antigenic alterations might also occur. The technique was to inactivate aliquots of a stock of type no. 6 with anti-T4 serum to a survival of 10^{-2} to 10^{-6} . Stocks were made from plaques resulting from the surviving phage particles. The rates of serological inactivation of these stocks were compared with the rate of inactivation of the original type no. 6. No significant differences were found in testing fifteen stocks derived in this way. These results suggest that the antigenic properties of these phages must be quite stable, or else that changes become manifest only after the accumulation of many changes, each of which is too small to be detected by these tests.

ORGANIZATION OF THE CHROMOSOME

B. P. KAUFMANN, M. R. McDONALD, H. GAY, N. C. OKUDA, J. M. PENNOYER, AND S. BLOWNEY

In our approach to problems of the nature and specificity of action of genes in higher organisms, we have continued to focus attention on details of chromosome organization. These studies, originally

formulated at the level of descriptive cytology, have in recent years been supplemented by experimental procedures involving ionizing radiations and chemical mutagens—used independently and in

combination with nonmutagenic agents, such as near infrared radiation—and purified enzymes. All these approaches have been employed in our studies during the past year, primary emphasis being placed on the cytochemical methods. Progress of the work has been facilitated by a research grant from the Division of Research Grants and Fellowships of the National Institutes of Health, U. S. Public Health Service.

CYTOCHEMICAL STUDIES

The cytochemical studies initiated three years ago (Year Book No. 45, 1945-1946) were projected on the assumption that precise information concerning fundamental patterns of cellular organization could be obtained by using purified enzymes in combination with various staining procedures. Since our interest in the gene focused attention on the nucleic acids and proteins, it was necessary to accumulate a stock pile of purified nucleases and proteases; and this requirement in turn led to the development of methods for the elimination of proteolytic contaminants from crystalline ribonuclease (Year Book No. 46). About a year ago Dr. M. Kunitz, of the Rockefeller Institute for Medical Research, published a method for preparing crystalline desoxyribonuclease; and application of his method has enabled us to obtain preparations of this enzyme that are free of measurable traces of proteolytic contaminants. These two nucleases, together with the proteases, trypsin, chymotrypsin, and pepsin, constitute the group of purified enzymes used in our cytochemical studies.

In employing the enzymes cytochemically it is also essential to maintain an extensive series of controls to determine the influence of all variables capable of influencing their hydrolytic activity or interfering with the staining reactions (Year

Books Nos. 46, 47). Only by maintenance of such controls has it been possible to attribute the results obtained to the specific action of the enzyme molecules on substrate molecules. The extreme care required is illustrated by an analysis of the factors involved in the process of dissolution of cells that follows their digestion in trypsin.

The course of tryptic digestion. It has been reported by a series of observers that either crude or purified preparations of trypsin degrade proteins and lead to disintegration of the cell. This type of result is readily demonstrable, as is shown in plate 1A. This section of a root tip of onion was treated with trypsin in 0.05 M phosphate buffer, pH 6, for one hour. No such dissolution occurred in the cells of an adjoining section of this root tip that served as a control and was treated only in the buffer. Because of previous experience with the complicating action of buffers in cytochemical reactions (see Year Book No. 46), it seemed essential in an analysis of the course of digestion by trypsin to determine to what extent cellular dissolution was referable to the presence of electrolytes rather than to the primary action of the enzyme in disrupting peptide linkages.

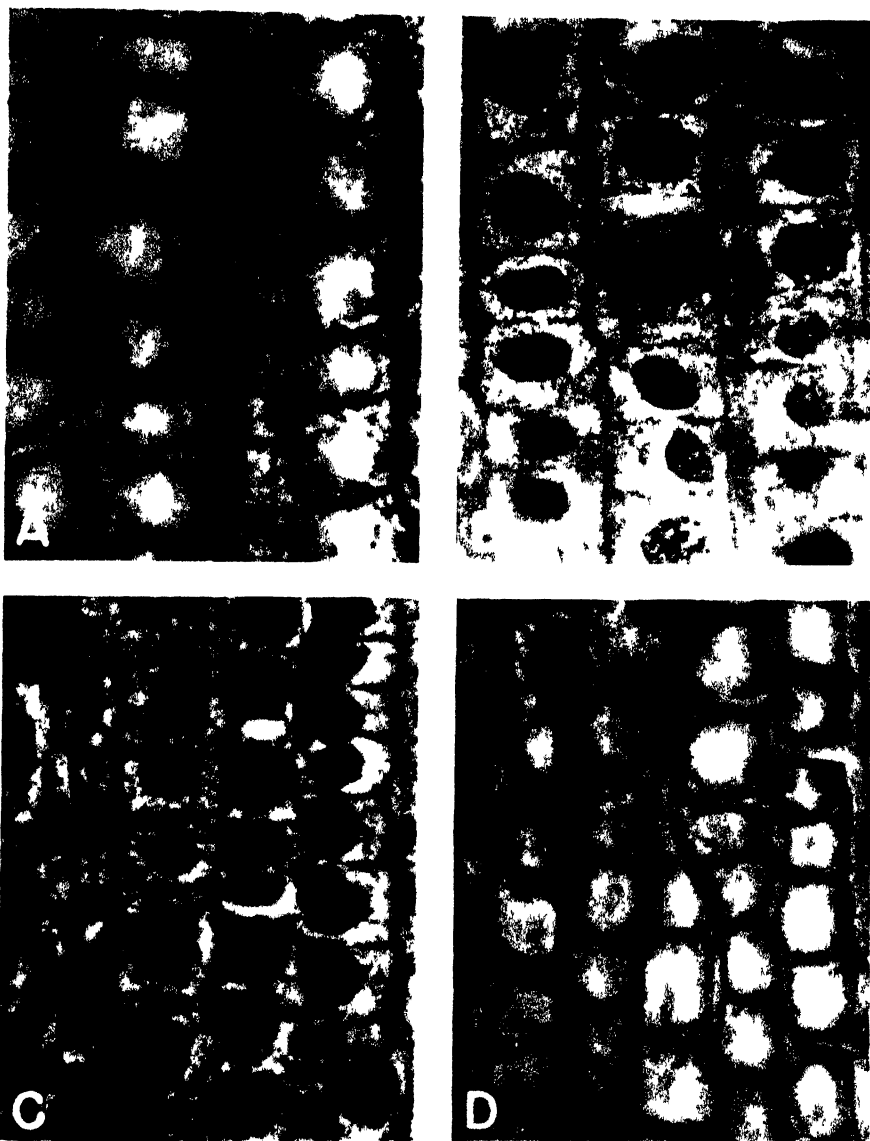
As a first step, it was necessary to determine whether trypsin causes cellular dissolution if used in the absence of electrolytes except for the traces necessary to adjust the pH. It was found that treatment of acetic-alcohol-fixed smears or sections for long periods of time with aqueous solutions of trypsin at pH 6 does not lead to cellular disintegration (pl. 1B). That trypsin is active in such solutions is suggested by increase in the stainability of the treated cells with pyronin and other basic dyes. One possible explanation of this increase is that pyronin-stainable nucleic acid is released by tryptic degradation of ribonucleo-

protein (Year Book No. 47). Aqueous solutions of trypsin also reduce the stainability with acidic dyes of the protein released by the action of ribonuclease on ribonucleoprotein (cf. Year Book No. 47). Additional evidence that aqueous solutions of trypsin are not impotent was provided by experiments in which treatment with such solutions was followed, after thorough rinsing, by treatment with 0.05 M phosphate buffer or by 0.04–0.10 M sodium chloride. Dissolution of cellular contents occurred rapidly under these conditions. Obviously the electrolytes play a decisive role in the process; but since treatment with buffers or salt was followed in all cases by prolonged washing in water, further experiments were required to determine the dependence of dissolution on removal of water-soluble materials. Accordingly, sections of root tips were treated with aqueous trypsin, then with phosphate buffer. If they were then transferred to 0.1 M hydrochloric acid before rinsing in water, the contents of the cells were preserved without apparent distortion (pl. 1C); but if they were rinsed in water before the treatment with hydrochloric acid, the cellular contents were not detectable (pl. 1D).

This phenomenon is strikingly demonstrated by using the phase-contrast microscope, which permits direct observation of gross alterations as they are induced by the various reagents. Immersion in aqueous trypsin (0.1 mg. per milliliter at pH 6 for 1 hour) does not effect any discernible structural alteration in salivary-gland chromosomes of *Chironomus* larvae (bloodworms). Even after prolonged washing in water, the precise pattern of banding is clearly defined. Upon subsequent addition of buffer or sodium chloride solution (in the concentrations indicated above), there occurs an immediate swelling of the chromosomes and separation of the bands

into their component chromomeres. If, at this stage, aceto-orcein is added, the chromosomes contract, and their bands once more become clearly defined and assume the purple color of the orcein stain. If, on the other hand, rinsing in water follows treatment with the buffer, the swelling continues until adjacent chromosomes adhere and their contents become disorganized. Continued washing leads to complete dissolution of cellular materials. It is apparent from this series of observations that the action of trypsin *per se* does not lead to the type of disintegration of substrate materials that has been attributed by other workers to specific disruption of peptide linkages. This in turn suggests a re-examination of the widely accepted concept that protein alone serves to maintain the form and structure of the chromosome. Aside from this application to problems of immediate importance in our cytochemical studies, these observations suggest a method of attack on more general problems of enzymatic digestion by resolving the process into its component phases.

Enzymatic dissection of the chromosome. Recent investigations, including those conducted in this laboratory (Year Books Nos. 46, 47), have indicated that the chromosomes of higher organisms contain histone and nonhistone proteins, and ribose and deoxyribose nucleic acids. Our cytochemical studies have indicated that ribonucleic acid is separable by enzymatic hydrolysis from a tryptophane-containing protein (Year Book No. 47); and chemical studies by various workers have shown that deoxyribonucleic acid is extractable from the chromosome in association with histone. Use of purified nucleases and proteases, independently and in combination with each other, or with various chemical procedures, should provide further information about patterns of association of nucleic acids and proteins as they exist separately and in



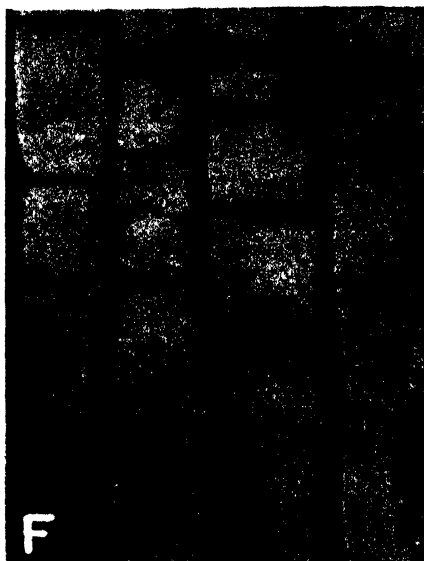
Tryptic digestion of onion root tip sections. 7-micron paraffin sections of root tip of onion, fixed in acetic alcohol, stained in methyl green pyronin — 860

A. Nuclear disintegration is produced by a solution of trypsin in buffer

B. Cells visibly intact after treatment with aqueous solution of trypsin

C. Retention of gross nuclear structure after successive treatments in aqueous solution of trypsin, in phosphate buffer, and in 0.1 M HCl

D. Nuclear disintegration produced by successive treatments in aqueous solution of trypsin phosphate buffer, water, and 0.1 M HCl



Pepsin digestion following removal of nucleic acids. 7 micron paraffin sections of root tip of onion, fixed in acetic alcohol, stained in fast green. $\times 860$

E. Extraction of all nucleic acids by treatment with 0.3 N trichloroacetic acid for 15 minutes at 90°C

F. The same treatment as E, followed by pepsin digestion

G. Degradation of nucleic acids by successive treatments with ribonuclease and desoxyribonuclease

H. Desoxyribonuclease treatment followed by pepsin digestion

combination within the fixed cell, and should also indicate whether or not their presence is essential for maintenance of structural integrity. It must be kept in mind that cellular materials are preserved by cytological fixatives without gross distortion of the spatial relations that exist in the living cell, and thereby provide a useful basis for initial studies of the chemical organization of the living system.

Trypsin presumably attacks peptide linkages involving basic amino acids that are present in both histones and nonhistone proteins. Chymotrypsin also seems to attack linkages common to both types of proteins, since the action of this enzyme in disrupting cellular organization has been found to parallel that reported above for trypsin. Differences that we have detected in potency and rate of action of the two enzymes promise to furnish information about the specific action of each on histones and other proteins. The evidence now available indicates that disruption of linkages in either type of protein by either of these enzymes (in concentrations as high as 1 mg. per ml.) does not destroy structural continuity of the chromosome unless treatment with the enzyme is supplemented by treatment with a solution containing electrolytes. The importance of different electrolytes in this process is now under investigation.

Pepsin is another proteolytic enzyme that has been used extensively in cytochemical studies. It effects a marked shrinkage of chromosomes without effacing their pattern of structural organization. Using the phase-contrast microscope, we have observed that pepsin in hydrochloric acid (3 mg. per ml. in 0.02 M HCl at 37° C.) will reduce salivary-gland chromosomes of *Drosophila* in 2 hours to about one-tenth of their original volume. On the basis of our studies and those of Mazia and his associates, it appears that the action of pep-

sin on fixed preparations consists primarily in degradation of the nonhistone, or tryptophane-containing, protein. If so, this substance represents a much higher proportion of the chromosome than would be expected from analysis of chemically isolated materials. From the standpoint of structural continuity, the histones and the nucleic acids surviving peptic digestion constitute a clearly defined although markedly shrunken chromosome.

Nucleases—that is, enzymes that degrade nucleic acids—also serve to reveal patterns of structural organization. Ribonuclease reduces stainability of ribonucleic acids with basic dyes, and also degrades ribonucleoprotein to release a protein that stains with acidic dyes (Year Book No. 47). Such treatment does not destroy chromosome structure; nor is it destroyed if treatment with ribonuclease is followed by treatment with pepsin.

Desoxyribonuclease eliminates stainability of chromosomes by the Feulgen method, indicating that this enzyme degrades desoxyribonucleic acid. The structure of the chromosome is not impaired thereby, since it is clearly defined when stained with acidic dyes. Structural continuity is also maintained if all nucleic acid is removed by consecutive treatments with ribonuclease and desoxyribonuclease, or by extraction with trichloroacetic acid at 90° C. (pl. 2G, E). If, however, treatment with pepsin follows either trichloroacetic acid extraction (pl. 2F) or treatment with ribonuclease and desoxyribonuclease, or even treatment with desoxyribonuclease alone (pl. 2H), dissolution of nuclear contents ensues. These results might seem to suggest the existence in the chromosome of two separable complexes, one ribonucleoprotein, the other desoxynucleohistone, either of which is capable in itself of maintaining the integrity of the chromosome. As was indicated in the experi-

ments using hot trichloroacetic acid or the nucleases in succession, however, both complexes may be degraded without effacing the chromosome.

The obvious conclusion from this series of experiments is that the proteins form an interrelated system in the chromosome, and that the nucleic acids are intimately linked with the proteins and perhaps with each other. On the basis of evidence now available, no single protein or nucleic acid may be regarded as the fundamental structural component of the chromosome.

RADIATION STUDIES

Our pioneering studies with near infrared radiation led to the discovery that wave lengths centering around $1\ \mu$ can modify the frequency of X-ray-induced chromosomal rearrangements, but not of gene mutations (Year Books Nos. 44-47). With the prospect that near infrared radiation might serve, when applied to organisms in which cytological analysis is not feasible, to distinguish between induced genetic changes that are attributable to chromosomal alterations and those that are not, a series of experiments was undertaken to determine the effects of near infrared rays and X-rays, used independently and in combination, on bacterial cells. In efforts to determine the nature of the "sensitizing" action of near infrared radiation, experiments were also initiated using systems less complex chemically than those of the living cell, namely, solutions of purified crystalline enzymes.

Response of the bacterium Escherichia coli to X-rays and near infrared rays. A series of studies was carried out, with the assistance of Miss Helen Cuneo, to compare the rates of mutation of the B/r strain of *E. coli* from the normal bacteriophage-sensitive condition to a phage-resistant state after treatment with X-rays

alone and after treatment with X-rays preceded by near infrared rays. As a prerequisite to this comparison it was necessary to determine the rate of survival of bacterial cells treated either with near infrared rays or with X-rays. Exposure to near infrared radiation (for periods of either 3 hours or 24 hours at 25°C.) of a culture of *E. coli* in a medium inadequate to permit growth (the solution of salts used in the M-9 medium) did not significantly alter the number of living cells or affect the proportion of mutants as compared with those of a control culture maintained in ordinary light at the same temperature. It thus appears that near infrared radiation alone has no lethal action and no mutagenic potency.

Treatment with X-rays kills bacteria in such proportions that exponential survival curves are obtained. It was found in a series of experiments that essentially a straight-line relationship was obtained when the logarithm of the surviving fraction of bacteria was plotted against the dose of X-rays, but that the slope of these survival curves varied greatly from experiment to experiment. When inocula from the same slant were grown under identical conditions for 48 hours, centrifuged to provide cultures containing approximately 10^{10} bacteria per milliliter, and irradiated under identical conditions at the same intensity, the inactivation doses of the separate cultures (amounts of radiation required to reduce the survivors to 36.8 per cent of the initial number) ranged between 8000 and 21,000 roentgen units. The basis of this variability remains to be determined, but apparently involves biological factors as well as those attributable to dosimetry and technical procedures.

Failure to establish a uniform survival curve has complicated the process of determination of mutation rates among the bacteria surviving X-ray treatment. Only

by assay over a wide range of dosage levels in any one experiment has it been possible to secure the required information. Two methods of measuring mutation rate were employed, namely, the zero-point technique developed by Demerec and Latarjet, and the liquid-culture, end-point technique developed by Newcombe (Year Books Nos. 45, 47). The results obtained by Demerec and Latarjet suggested that mutation rate is proportional to X-ray dosage. The results obtained in our studies were too variable to provide significant statistical verification of this interpretation; in some experiments the mutation frequency was significantly higher than in untreated controls, whereas in others it was not.

The mutation rates in the bacterial populations treated with near infrared rays plus X-rays and in those treated with X-rays alone were not appreciably different in paired experiments. Again, there was considerable variability from experiment to experiment, and more data must be amassed to permit reliable statistical analysis. Inferences concerning the relation of X-ray-induced mutants to chromosomal aberrations in *E. coli* cannot be made until such information is obtained.

The effect of X-radiation on dilute solutions of crystalline trypsin. It has been known for many years that the activity of enzymes can be destroyed by X-radiation. Large doses were necessary, however, for such destruction, and it was therefore generally believed that enzymes were too insensitive to radiation to account for the radiation effects noted in the living cell. In 1940, however, W. M. Dale found that "the effect of X-rays on aqueous solutions of enzymes and of other biologically active compounds depends on the concentration and purity of such solutions, and that doses of as little as 50 roentgens can produce marked effects when concentrations of the order of those occurring in living

cells are irradiated." Work in several other laboratories has since confirmed these general conclusions. Dale postulated that enzyme molecules are affected by the ionizing radiation, not directly, but indirectly through collision with a labile product resulting from ionization of the water. Very little is known about the action of infrared radiation on enzymes. It has been reported as destroying urease, stimulating starch amylase, and having no apparent effect on pepsin. Unfortunately, the experiments on which these reports were based were done with impure enzyme preparations. In our work we have used purified enzymes prepared in our laboratory. The work with near infrared radiation is still too preliminary to warrant even tentative conclusions. We shall therefore report at this time only the results obtained with X-rays on solutions of crystalline trypsin.

Crystalline trypsin was chosen for the original studies for several reasons. In the first place, it can be accurately assayed, permitting precise reproducibility of results. It is stable at pH 2.4, thus eliminating any complicating secondary effects due to spontaneous inactivation. Finally, it appeared to be a suitable enzyme for comparison with carboxypeptidase, the only purified enzyme on which extensive quantitative data were already available, because both enzymes are primarily peptidases, their source is beef pancreas, and their molecular weights are similar (trypsin = 36,500; carboxypeptidase = 35,000).

The effect of X-radiation on solutions of crystalline trypsin in 0.005 N hydrochloric acid has been determined under a variety of conditions, such as varying the radiation dosage while the concentration of trypsin remains constant, varying the concentration of trypsin while the dosage remains constant, and varying both the concentration of trypsin and the dosage, the ratio

of the two being constant. Inactivation has been observed with doses as low as 100 roentgens. As has generally been found for proteins, however, the greater the initial concentration of trypsin, the larger is the dose of radiation necessary for comparable percentages of inactivation. For any given initial concentration of trypsin, the decrease in tryptic activity with increasing amounts of radiation is exponential. It is therefore essential, when comparing various experiments, to do so at a constant level of inactivation. For convenience both of calculation and of comparison with other published data, this level has been taken as 63.2 per cent, the amount of radiation necessary to produce this percentage of inactivation being known as the "inactivation" dose. Calculations of "inactivation" doses show that they increase with increasing initial concentrations of trypsin, but that the increase is not directly proportional in the range of trypsin concentrations so far studied (1.2–344 $\mu\text{g. per ml.}$). This means that in this range of concentrations the ionic yield—i.e., the number of molecules destroyed per ion pair—is not constant. For example, under otherwise identical conditions, the ionic yield for a 9×10^{-8} molar solution of trypsin (3.29 $\mu\text{g. per ml.}$) was found to be 0.0074, whereas for a 9.4×10^{-6} molar solution (344 $\mu\text{g. per ml.}$) it was 0.0376. Drops in ionic yields at low solute concentrations have been noted in other laboratories in studies of the effects of X-rays on oxalic acid, methyl alcohol, glutathione, tobacco mosaic virus, and rabbit papilloma virus. Such results would be expected, according to the "indirect action theory" of the effects of radiation, if the solute concentration is so low that an appreciable proportion of the total number of "active radicals" combine with one another rather than react with the solute molecules. Absolute ionic yields therefore

cannot be stated for radiation effects in very dilute solutions, unless one has ascertained by experiments over a wide range of solute concentrations that they are constant or can be extrapolated from the data. Unfortunately, this has not generally been done, and many of the values for ionic yields given in the literature may therefore be misleading. Barron *et al.*, for example, state that the ionic yield for the inactivation of trypsin by X-rays is 0.025. This value was determined, however, from one experiment at one concentration (50 $\mu\text{g. per ml.}$) and can apply only to that specific case.

Dale noted in his original studies (1940–1943) on the inactivation of carboxypeptidase by X-radiation that, over a wide range of dosage (50 to 400,000 r) and enzyme concentrations (calculated by us from his data to be approximately 1.6 to 540 $\mu\text{g. per ml.}$), the number of enzyme units inactivated by a given number of roentgens and for a given percentage of inactivation was constant. As noted above, in experiments using a similar range of enzyme concentrations (1.2 to 344 $\mu\text{g. per ml.}$) and of X-ray dosage (100 to 100,000 r) no constant value was found for trypsin. This indicated a marked difference between the two enzymes. Since our experiments were completed, however, Dale and his co-workers (1949) have published extended data covering an extremely wide range of carboxypeptidase concentrations, namely from 5 to 150,000 $\mu\text{g. per ml.}$ Here they report that for concentrations below approximately 200 $\mu\text{g. per ml.}$ the ionic yield decreases markedly with decreasing concentrations, although at higher concentrations it is approximately constant and equal to 0.18 enzyme molecule inactivated per ion pair. They obtained similar results with alloxazine adenine dinucleotide.

X-rayed 0.005 N hydrochloric acid was found to have no effect on the activity of

solutions of crystalline trypsin. A solution of trypsin, dissolved in hydrochloric acid that had received 35,000 roentgens immediately before use, when assayed after 4 hours at 25° C. had 623×10^{-6} trypsin units (denatured hemoglobin); whereas control solutions in hydrochloric acid that had not been X-rayed had 616×10^{-6} units. Such a solution of trypsin would have lost 84 per cent of its activity had it received this amount of X-radiation directly.

There appears to be no delayed effect, such as R. S. Anderson found with pepsin. nor is there any spontaneous recovery either in the light or in the dark. For example, a solution of trypsin (33 µg. per ml.) that received 18,000 r had, when assayed immediately after radiation, 285×10^{-6} activity units. After 1, 5, and 24 hours at 0° C. in light and in dark, the assays were 285, 285, and 283×10^{-6} units, respectively, for light, and 285, 285, and 286×10^{-6} units for dark.

The rate of inactivation of crystalline trypsin by X-radiation was found to be independent of the intensity at which the radiation was delivered. Inactivation doses for a solution of crystalline trypsin containing 30.4 µg. per ml. were 21,500, 21,200, 20,750, and 21,500 r with rates of delivery of 581, 264, 180, and 129 r per minute, respectively.

All the experiments reported thus far have been carried out at pH 2.4, the point of maximum stability for trypsin. Preliminary experiments indicate that the hydrogen ion concentration of the solution being irradiated affects the amount of inactivation. As yet, however, the optimum pH for X-ray inactivation of trypsin has not been established.

The nature of the change in the trypsin molecule responsible for the loss of activity brought about by irradiation is unknown. It is hoped that an extension of these data

to include trypsinogen, the precursor of trypsin, may shed some light on this problem, as well as on the even more basic problem of what group or groups in the trypsin molecule are responsible for its specific action.

Studies combining treatments with near infrared radiation and nitrogen mustard. As reported in preliminary form in Year Book No. 47, near infrared radiation, when used before nitrogen mustard in treatment of males of *Drosophila melanogaster*, effects an increase over the nitrogen-mustard-treated controls in frequency of chromosomal rearrangements, as determined by genetic tests for translocations between the second and third chromosomes. Posttreatment, on the contrary, does not produce any increase in frequency.

The data obtained in these studies have been subjected during the past year to critical statistical analysis. Since in the pretreatment series five separate groups of flies were exposed to the aerosol of nitrogen mustard, and since each was mated with three groups of females at 6-day intervals, fifteen samples were available for comparison between the infrared-treated flies and their controls. Disproportionate frequencies, and the interaction of the five separate treatments and the three transfers, posed a statistical problem: that was solved, at the suggestion of Dr. A. E. Brandt of the Atomic Energy Commission, by use of the method of partitioning of chi square. The analysis indicates that the differences between the separate treatments and the different transfers are significant. The least-square lines derived from the total data are shown in figure 3. These lines have essentially the same slope. Analysis reveals that the percentages of translocations represented in the experimental and control regression lines differ significantly from each other. The data thus indicate

that pretreatment with near infrared radiation effects an increase of about 50 per cent in the frequency of mustard-induced chromosomal translocations; and this increase corresponds closely to the value obtained in earlier experiments in which near infrared pretreatment was used with X-rays.

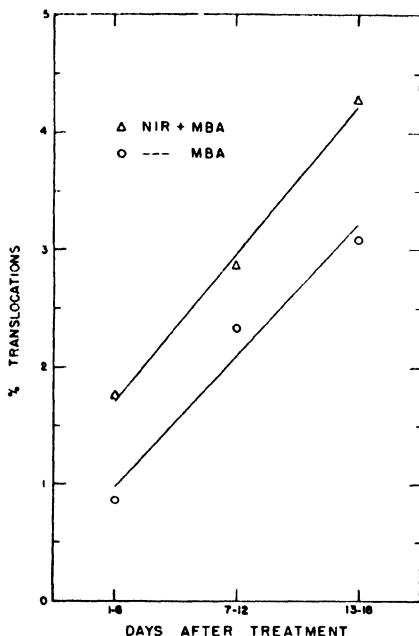


FIG. 3. Least-square lines, for pretreatment series and its controls, derived from frequencies of nitrogen mustard-induced translocations between the second and third chromosomes of *Drosophila melanogaster*. Upper line, near infrared radiation followed by nitrogen mustard; lower line, nitrogen mustard control.

Comparable statistical analysis applied to the posttreatment data indicates that the differences between successive transfers are significant, but that near infrared radiation does not significantly modify the frequency of translocations when it is used after the

nitrogen mustard. This result also agrees with that obtained in the earlier experiments in which near infrared radiation was used after X-rays.

An effort was next made to determine whether the increased frequency of translocations detected in successive transfers was due to a cumulative action of the chemical on spermatozoa that were mature at the time of treatment, or to an effect on cells that were in earlier stages of develop-

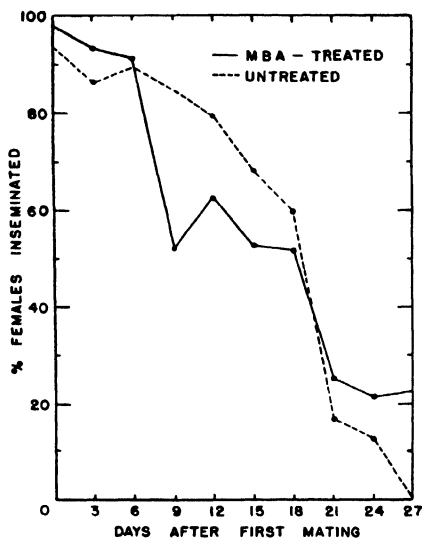


FIG. 4. Proportion of available females inseminated by nitrogen mustard-treated and untreated males at successive three-day intervals after the first mating.

ment at that time. Preliminary experiments were undertaken to determine the length of time after treatment that males remain fertile, as indicated by their capacity to inseminate females and by the progress of spermatogenesis. These studies showed that spermatogenesis is not necessarily terminated by exposure of males to mutagenically potent doses of nitrogen mustard. Cytological examination of sec-

tions of testes dissected from sexually active and inactive males throughout a 30-day period revealed dividing spermatogonia and spermatocytes and an abundance of mature spermatozoa in both. The proportion of available females inseminated by treated males is shown in figure 4. In obtaining these data, each male was mated with 3 virgin females immediately after treatment, and at the end of each 3 days thereafter. Males of the same cultures that had not been exposed to the aerosol of nitrogen mustard served as controls. A comparison of the two curves shown in figure 4 suggests that exposure to nitrogen mustard may temporarily impair sexual

activity, but that recovery occurs in a high proportion of treated males.

Additional work will be required, however, to answer the question whether the higher frequency of translocations detected in later transfers is due primarily to an effect of the chemical on mature germ cells or on immature germ cells. In the latter event, the possibility must be examined that the mustard-induced rearrangements arise in large part as chromosomal mosaics, and that the higher frequency observed in later transfers is due to the facilitation of their detection by the experimental procedure used. Experiments designed to answer this question have been initiated.

MOUSE LEUKEMIA

E. C. MACDOWELL, M. J. TAYLOR, AND L. E. LEWIS

Increasing potency of an invading pathogenic agent or transplanted tumor has frequently been observed to be closely connected with a change in the range of susceptible hosts. Thus the increase in virulence of line-I leukemia seemed to provide a valid reason for the apparent failure of the natural resistance of mice from foreign strain StoLi. During its first hundred passages, line I failed to kill any of its hosts from this strain, but by transfer 147 it was killing a large proportion of these mice.

That the line-I leukemic cells proliferated in these StoLi hosts, and were successfully carried in mice of this strain for a series of 14 successive transfers, seemed ample evidence that leukemia was the cause of death. The difference in genetic constitution between the hosts of this strain and the strain of origin provided a reasonable interpretation of the observed modifications in metabolism of the invaded lymph nodes and in cytological details of the invading cells; for upon subsequent transfer to hosts of the original strain, all the specific characteristics of line-I leu-

kemia, including metabolic rates and cytological details, reappeared. When these interpretations were proposed, the possible association of a virus with line-I leukemia was not even imagined. The two previous reports have recorded the isolation of a virus from line I and the freeing of line I from the virus, which now appears almost certainly to have been transplanted along with the leukemic cells for ten or more years.

Work of the current year with line I, freed from the virus, shows that the virus and not the increased virulence of the leukemic cells was responsible for the death of the StoLi hosts. With the virus eliminated, every StoLi (91) inoculated with line-I leukemic cells has survived, as during the earliest period of this project. But these mice are highly susceptible to the virus, which induces a more violent sickness than in C58 mice and kills every mouse. Thus, strain StoLi is killed by the virus and not by line I, and strain C58 is killed by line I but not by the virus, although an initial proliferation of the re-

spective pathogens occurs in the survivors in each case.

At the time StoLi mice were dying after inoculation with line I, the ratio of deaths in mice of the backcross generation, (C58 \times StoLi) \times StoLi, rose from the previous fully confirmed Mendelian 1:1 to 4:1. This year, mice (120) of this same backcross generation, when inoculated with line I free from virus, but with virulence as great as ever, once more gave the classic 1:1 ratio (50.8 per cent survived). This ratio is consistently indicated when the data are subdivided according to (1) the four types of matings (reciprocal F₁'s, reciprocally backcrossed to StoLi), (2) three pairs of color genes, and (3) sex. Thus it appears that the natural resistance of StoLi to line-I leukemia, and the primary dependence of this resistance upon a recessive gene, are once again demonstrable; and it is highly probable that at no time was there a failure of this resistance.

The discovery that an unsuspected virus was responsible for changing the proportion of line-I survivors in a foreign strain and in a backcross does not forthwith demonstrate that all the changes in such proportions that we have observed within other lines in the course of many transfers, and all the differences between lines according to these criteria, can be explained by the intermediation of a virus. For instance, line L, which arose in strain 89 and was long carried by hosts of this strain, killed only 1 per cent of the 92 mice of strain C58 tested in the first 15 transfers, whereas the hosts of strain 89 were all susceptible throughout. With the line-L cells carried exclusively by strain-89 hosts, the proportion of susceptible C58 mice rose by degrees to 95 per cent in the course of 60 successive transfers. Considerably later, line L was found to kill 100 per cent of C58 mice, and for the last 480 transfers

this line of leukemic cells has been routinely carried by C58 mice which have maintained 100 per cent susceptibility.

We have previously reported that line L was found to be carrying a virus, and that the leukemic cells of this line had been freed of this virus. Contrary to the situation found with line I in strain StoLi, however, the elimination of the virus from line L has left the 100 per cent susceptibility of strain C58 unchanged. In this case, changes in the leukemic cells, and not the presence of a virus, were responsible for the changes in the susceptibility of strain C58.

Furthermore, lines E and H after 90-odd transfers in the hosts of the strain of origin (C58) gave susceptibility ratios, in mice of the above-mentioned backcross, that approached 1:1, thus resembling the virus-free line I. Earlier in their histories these two lines showed only 10 to 15 per cent susceptibility in the backcross.

However indicative these previous observations might be, the point seemed of sufficient importance to make a backcross test of susceptibility to leukemic cells that had passed through only a single transfer after removal from a spontaneous case of leukemia. Accordingly, a group of 102 mice of this same backcross were thus inoculated. In the case of line I, the susceptible backcross mice died at the same time and showed the same autopsy picture as the C58 controls; in this case, the intervals before death were so continuously variable and so often greatly prolonged beyond the C58 controls that no sharp line could be drawn between susceptible mice and survivors. Of the C58 controls, 14 died after 13 to 17 days and one after 45 days; of the backcross hosts, 2 died before the 20th day, and the following numbers in successive 10-day periods: 1, 3, 2, 1, 6. At 72 days, observations were discontinued and the remaining mice killed; at this

time the autopsies gave definite evidence of leukemic infiltration in 4 and probable initial stages in 2 others. Although longer observation might have added cases still more delayed, there was no approach to a 1:1 ratio of resistant to susceptible animals, and the contrast with line-I leukemia seemed sufficiently well established. Various degrees of resistance were indicated not only by the intervals before death, but also by the distribution of lesions in the backcross animals. Only 4 of these showed the general enlargements of spleen and nodes found consistently in the C58 controls. In the great majority of cases the backcross autopsies revealed a strong but highly variable concentration of leukemic infiltration in deep lymph nodes and organs (notably the ovary), whereas the superficial nodes and spleen remained relatively small. Obviously, these leukemic cells are resisted in varying degrees by most of the 50 per cent of the backcross mice that are susceptible to line-I leukemia by virtue of their genetic constitution; and it may be concluded that in regard to host susceptibility and resistance these leukemic cells, in their second passage from a spontaneous case, are intrinsically different from cells of line I.

A MILK FACTOR RESISTING SPONTANEOUS LEUKEMIA AND LENGTHENING LIFE

It has been confirmed this year that a resistance factor from mothers of the non-leukemic strain StoLi, rather than a leukemia-inducing factor from mothers of the leukemic strain C58, is responsible for the differing incidence of spontaneous leukemia among animals from reciprocal matings between these two strains. This resistance is transmitted to their hybrid young by mothers over 34 weeks old, but not by young mothers 10 to 18 weeks old. Year Book No. 46 (1946-1947) reported

preliminary results of the experiment designed to verify this mother's-age effect, which had first been recognized in an earlier experiment. The final results show that, with all fathers from the leukemic strain and each one mated to both young and old StoLi mothers, the incidence of leukemia was unquestionably lower in the hybrids from old mothers than in the hybrids from young mothers, and the lives of both leukemics and nonleukemics were lengthened. With young mothers, the final incidence of leukemia, after questionable cases were checked microscopically, was 82.6 per cent of 75 mice; with old mothers, it was 56.8 per cent of 88 mice. The young-mothers group lived from 309 to 891 days (average 595.7 days), with 32 per cent dying between 550 and 650 days; the old-mothers group lived from 546 to 1107 days (average 817.5 days), with 34 per cent dying between 850 and 950 days. The reduction in the incidence of leukemia was direct, and not secondary to the effect on longevity; for longer lives were associated with less rather than more leukemia, and the mother's-age effect on longevity was as certainly manifested by the non-leukemics as by the leukemics.

In the above experiment each mother nursed her own young, but in the next experiment, set up in 1947 (Year Book No. 46), with the same two groups of hybrids from young and old StoLi mothers, some of each group were nursed by their own mothers and some by mothers of the other age group. Although final results are not expected for another year or more, the observations up to date are highly important and significant, leaving little doubt of the validity of the general conclusion that the resistance factor from old mothers can be transmitted by nursing alone quite as effectively as before birth. The control groups from young mothers with young nurses, and old mothers with old nurses,

have closely repeated, up through the 650-day class, the curves of cumulative leukemic incidence by 50-day classes given by the earlier experiments, the gross diagnoses up to date indicating leukemia in 60.8 per cent of the entire group of 120 hybrids from young mothers and young nurses, and in 13.1 per cent of the group of 84 hybrids from old mothers and old nurses. The curve for the critical group, mice from young mothers and old nurses, almost exactly equals that for the old mothers-old nurses group, at 650 days showing leukemia in 11.0 per cent of the group of 109. In terms of those that have already died, the young-young group has yielded 81.6 per cent leukemia, and the young-old group 50 per cent leukemia; these figures are very close to the expected final inci-

dences. The difference in longevity is indicated by death, up to date, of 83.3 per cent of the young-young group against 41.3 per cent of the young-old group.

However real, the resistance to leukemia that depends on the advanced age of the StoLi mother or nurse is clearly not highly potent, in that the incidence is not reduced by even one-half. Yet the discovery of the mechanism by which this moderate reduction in incidence is brought about may well lead to further understanding, if not control, of the manifestation of an inherited tendency to leukemia. On the other hand, the discovery of the mechanism responsible for lengthening life to the extent of 33 per cent by a factor in old nurses' milk would have considerably broader implications.

GENIC ACTION

E. CASPARI AND H. C. DALTON

Analysis of the action mechanism of individual genes has been continued. Besides the genes studied previously—that is, *a* (red eyes) and *wa* (white eyes) in the moth *Ephestia*, and *T*, *Ki*, and *Fu* (tail malformations) in the mouse—the gene *Δ* (white color) in the Mexican axolotl was included in our studies. In addition to the genetic and biochemical methods used previously, the embryological methods of explantation and transplantation were employed; and immunological methods were successfully used for the identification of genetic differences.

We wish to thank Miss Louise Pool for her valuable help in carrying out these investigations. During the summer we were assisted by Misses Louise H. Earle and Barbara C. Wolff and Mr. Noel H. Miller.

MATERNAL EFFECT OF *Fu*

Fu in the mouse is a dominant gene with variable expression. As described

previously (Year Book No. 47, 1947-1948), the number of phenotypically Fused animals is lower in crosses of *Fu*/+ females by +/+ males than in the reciprocal cross. Evidence seemed to indicate that this phenomenon might be due to the existence in different proportions of *Fu*/+ animals that were phenotypically normal. This hypothesis was investigated by individual test matings of normal animals from crosses involving *Fu*.

The *Fu* strain had previously been outcrossed for 20 to 22 generations to a normal, highly inbred Bagg albino strain. Normal-tailed progeny from crosses of *Fu*/+ females by Bagg albino males and Bagg albino females by *Fu*/+ males were outcrossed to Bagg albino animals. The offspring were observed at birth and discarded, except in unusual or doubtful cases. Animals giving one or more offspring with definitely abnormal tails were counted as genetically *Fu*/+, whereas animals that had at least 22 normal and no Fused off-

spring were counted as $+/+$. This limit of significance was chosen because the cross $Fu/+$ female by $+/+$ male gives about 30 per cent phenotypically Fused offspring. With this ratio, the probability of obtaining no $Fu/+$ offspring from a $Fu/+$ mother by chance only would be about 0.0001. Actually, in most cases more than 30 offspring were obtained.

The results of these crosses are given in table 5. The expectations given in column 4 were calculated from the number of phenotypically Fused animals obtained

studying the offspring from individual animals. All "normal overlaps" from the cross $Fu/+$ female by $+/+$ male and from the F_2 gave a reasonably high number of Fused progeny, similar to that produced by phenotypically Fused heterozygotes. Six of the offspring from the cross $+/+$ female by $Fu/+$ male, on the other hand, gave highly abnormal ratios (male no. 683: 51 normal, 1 Fused; male no. 678: 42 normal, 3 Fused; male no. 1565: 116 normal, 1 Fused; female no. 642: 43 normal, 1 Fused; female no. 685: 55

TABLE 5
PROGENY TESTS OF NORMAL ANIMALS FROM CROSSES INVOLVING Fu

Cross	Genetically		Per cent Fused		χ^2 (d.f. = 1)	P
	Normal	Fused	Observed	Expected		
1. ♀ $Fu/+$ × ♂ $+/+$	60	21	25.9	28.0	0.177	~ 0.7
2. ♀ $+/+$ × ♂ $Fu/+$	45	11	19.7	10.0	7.48	< 0.01
2a. ♀ $+/+$ × ♂ $Fu/+$ (corrected)	51	5	8.9	10.0	0.175	~ 0.7
3. ♀ $Fu/+$ × ♂ $Fu/+$	9	6	40.0	33.8	1.54	~ 0.2

previously from the respective crosses, on the assumption that the actual numbers of $Fu/+$ and $+/+$ offspring were equal, and that the deviations from a 1:1 ratio were due only to the occurrence of phenotypically normal $Fu/+$ animals. Table 5 indicates that the offspring from $Fu/+$ female by $+/+$ male crosses and from $Fu/+$ female by $Fu/+$ male crosses fitted this expectation. Progeny from the cross $+/+$ female by $Fu/+$ male included a significantly higher proportion of animals giving Fused offspring than was expected. The difference between the proportions of $Fu/+$ offspring from crosses 1 and 2 is not significant ($\chi^2 = 0.745$, d.f. = 1, $P \sim 0.4$).

This discrepancy between result and expectation in progeny from the cross $+/+$ female by $Fu/+$ male can be resolved by

normal, 4 Fused, all in the same litter; female no. 421: 55 normal, 2 Fused). Ratios of this type have not been obtained from other crosses involving $Fu/+$ animals, either phenotypically normal or Fused. The question arises, therefore, whether these animals actually are genetically $Fu/+$, or whether they are $+/+$ animals that occasionally give offspring with kinky tails.

If these animals are genetically $Fu/+$, they may be assumed to carry modifiers that suppress the penetrance of the gene Fu . In this case, about half of their normal offspring should carry the gene Fu . Since there is no evidence for the existence of such modifiers in the Bagg albino strain, outcrosses to Bagg albinos should result in the appearance of Fused offspring in about half of the crosses. Actually, from 24

normal progeny of animals giving abnormal ratios, 450 normal and no Fused offspring were obtained. Similarly, if animals carrying modifiers leading to the suppression of the Fused character were crossed to *Fu*/+ animals, a reduction of the number of Fused offspring would be expected. Males 653 and 1565 were outcrossed to *Fu*/+ females, and produced 40 normal and 16 Fused progeny. This ratio is not significantly different from that usually obtained from a cross of *Fu*/+ female by +/+ male.

The "Fused" offspring from animals giving abnormal ratios cannot be differentiated phenotypically from *Fu*/+. The expression of the character is good; in one case it was even stronger than is usual in *Fu*/+ heterozygotes. Two of these animals were reared and bred. Crossed out to normal Bagg albino females, they produced 60 normal and no Fused offspring. Thus they behaved in crosses as genetically +/+, and may be regarded as "Fused overlaps," that is, normal animals exhibiting the Fused phenotype.

The parents of these "Fused overlaps," which otherwise had only normal offspring, must therefore be considered as genetically +/+. It may be assumed that the other 4 animals that gave abnormal ratios, whose Fused offspring were not progeny tested, were also genetically normal. If this assumption is accepted, the values in line 2a of table 5 are obtained. With this correction, the agreement between expectation and results is good. Furthermore, the difference between the percentages of genotypically *Fu*/+ animals from crosses of *Fu*/+ females by +/+ males and from crosses of +/+ females by *Fu*/+ males (lines 1 and 2a, table 5) is significant ($\chi^2=4.917$, d.f.=1, $P=0.025$).

Kinky-tailed animals resembling the Fused phenotype occur occasionally in

normal strains. The question arises, therefore, whether the proportion of "Fused overlaps" is greater in the progeny of normal animals from the cross +/+ female by *Fu*/+ male than in the normal strain. Assuming that the animals giving abnormal ratios are normal, and their phenotypically Fused offspring are "overlaps," 10 "Fused overlaps" have been obtained among 1457 offspring (0.686 per cent). The lower fiducial limit at the 1 per cent level for this ratio would be 0.331 per cent. A comparison may best be made with the offspring of normal animals from the cross *Fu*/+ females by +/+ males. Among 958 progeny of this type no "Fused overlaps" were found. It therefore appears with a high degree of significance that particular conditions exist in normal animals from the cross +/+ females by *Fu*/+ males that occasionally result in the appearance of "Fused overlaps."

The results of these experiments demonstrate that the maternal effect of *Fu* is actually due to differential overlapping. *Fu*/+ mothers influence Fused ova or embryos in such a way as to decrease the penetrance of the gene *Fu*.

TRANSPLANTATION OF EMBRYONIC TAILS IN THE MOUSE

In order to be able to analyze the action of the genes *T*, *Fu*, and *Ki*, we developed a method that allowed us to grow tails of young mouse embryos in the anterior chamber of the eye of adult mice.

The mouse embryos were timed by the vaginal-plug method. Nine to 12 days after the vaginal plug had been observed, the mothers were killed with chloroform and the uteri dissected out and kept in mammalian Ringer's solution at 37° C. The embryos were taken out of the uterus and pieces of the tail or tail bud were cut

off with glass needles. Usually two pieces were prepared from each embryo, one containing the extreme tip of the tail and the other a more proximal section. In some cases pieces were further dissected by a cut dividing the dorsal from the ventral part of the section, so as to obtain pieces that presumably lacked the neural tube and pieces that carried large amounts of neural tube.

The mice used as hosts were mostly Bagg albinos. In some cases strain-C58 and strain-89 mice were used. The hosts were anesthetized by subcutaneous injections with nembutal. Definite strain differences in sensitivity to nembutal were found; C58 mice frequently died of doses that produced anesthesia but not death in Bagg albinos. An incision was made, with an iridectomy scalpel, through the cornea near the dorsal border of the sclera. The transplant was introduced into the anterior chamber in a drop of Ringer's solution by means of a Spemann micropipette. Preliminary attempts to use a metal trocar for transferring the piece of tissue were unsuccessful, because the tissue tended to cling to the metal surface. Usually the transplant was moved, by gentle pressure on the cornea, to the ventral border between iris and cornea.

All operations were carried out under sterile conditions. The Petri dishes used for dissection of the embryos were sterilized by dry heat, the Ringer's solution in the autoclave. The metal instruments for the dissection of embryos were soaked for $\frac{1}{2}$ hour in Zephiran chloride and washed in several changes of sterile Ringer's solution. The glass instruments were dipped in alcohol and washed in sterile Ringer's solution between operations. In many cases the cornea of the host was washed with dilute Zephiran chloride (1:10,000).

The explants were kept in the host for 4 to 5 days; then the host was sacrificed

and the eyes removed. The transplant was dissected out and fixed in Carnoy, or else the eye was fixed in toto. They were then sectioned and stained with hematoxylin-eosin or with azan.

In spite of the sterile precautions, the eye was frequently infected, as judged by the opacity of the cornea or lens. On the whole, 41 out of 110 eyes appeared to be infected. The infection did not interfere significantly with the growth of the transplant ($\chi^2 = 0.275$, $P = < 0.50$). There is no evidence that proximal pieces of the tail grew better than the extreme tail tips ($\chi^2 = 0.259$, $P = < 0.50$). There was no evidence of differences in survival according to the genotype of the graft (heterogeneity $\chi^2 = 2.957$, d.f. = 4, $P = < 0.50$).

After 4 to 5 days in the host eye, at least some of the grafts showed definite increase in size. All of them showed a certain amount of organization, although the degree was different in different cases. In the best-developed pieces, as shown in plate 3, the neural tube, notochord, and tail gut, in the correct arrangements, could be distinguished. The mesenchyme was sometimes arranged in a structure similar to somites, lateral to the neural tube (pl. 3). The mesenchyme surrounding the notochord frequently assumed a histological structure suggestive of precartilag (pl. 4B).

Grafts from embryos with Bagg albino normal, *T*, and *Ki* parents showed no particular characteristics of differentiation that could be associated with these genes. In grafts from embryos with *Fu* parents, however, although differentiating somite material looked healthy, the notochord and neural tube were either missing altogether or small and poorly differentiated.

Plate 4A illustrates the amount of growth attained by some transplanted tissues. The donor, from a cross of normal

by Kinky, was 9 days old at the time of operation. A small dorsal piece of the tail bud, containing practically nothing but neural plate, was allowed to remain 4 days in the host. Comparison of this neural tube with that of plate 3, which is represented at the same magnification, will give an indication of the growth in this transplant.

An apparent case of induction is illustrated in plate 4B. The graft was a proximal ventral piece of tail from a normal embryo from a mating of *Ki* by *Ki*, 11 days old. It contained somite material from the right side, probably including pieces of notochord but certainly no neural tube. After 5 days in the host the transplant, on sectioning, presented the appearance shown in the plate. There is visible a centrally placed notochord surrounded by concentrically arranged mesenchyme cells, which look like precartilag. Adjacent to this, at the edge of the transplant, is a tuberos structure resembling a neural tube. Although it cannot be stated with certainty that no trace of neural-tube tissue remained in the explanted piece, it appears very likely that this structure was induced by the transplanted tissue.

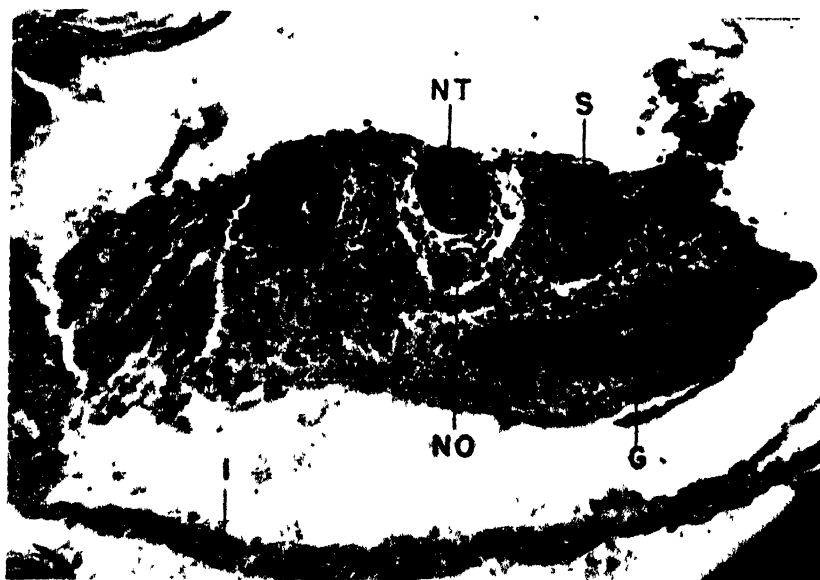
GENE ACTION IN THE AXOLOTL

Amphibian pigment cells offer advantages for the analysis of genic action, because their developmental origin in the neural crest and the subsequent establishment of the larval pigment pattern by migration through the embryonic tissues make possible two types of experimental attack on the problem. First, by explanting in hanging-drop tissue cultures dorsal pieces of neural fold from early neurulae one can obtain isolates of neural-crest material, which in the posterior trunk region consist largely of potential chromatophores. These pro-pigment cells move out from the explants onto the cover glasses, permit-

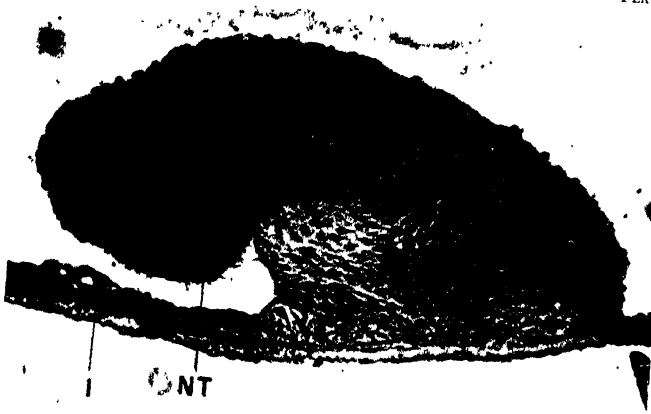
ting direct observation of their intrinsic capacities for migration, proliferation, and pigment synthesis under controlled conditions. Second, by methods of embryonic transplantation one can test reactions between potential pigment cells and their embryonic environment, observing factors extrinsic to the chromatophores themselves but important for pigment synthesis and cell migration. Combining these methods, it is possible first to localize the seat of gene action in the embryo and then to attack the problem of analyzing the nature of this action.

The genes selected for this investigation are those responsible for the pigment patterns characteristic of the white (*dd*) and black (*DD*) strains of the Mexican axolotl *Siredon mexicanum*. It has long been known that these patterns of pigmentation are associated with a single pair of alleles showing Mendelian segregation, the white condition being recessive. Embryonic transplantation experiments described in the literature have suggested that genic action in this case is mediated through the epidermis, which in the white genotype fails to provide some diffusible substance necessary for melanin synthesis. The present investigation was undertaken to determine more precisely the nature of this epidermis effect on pigment development.

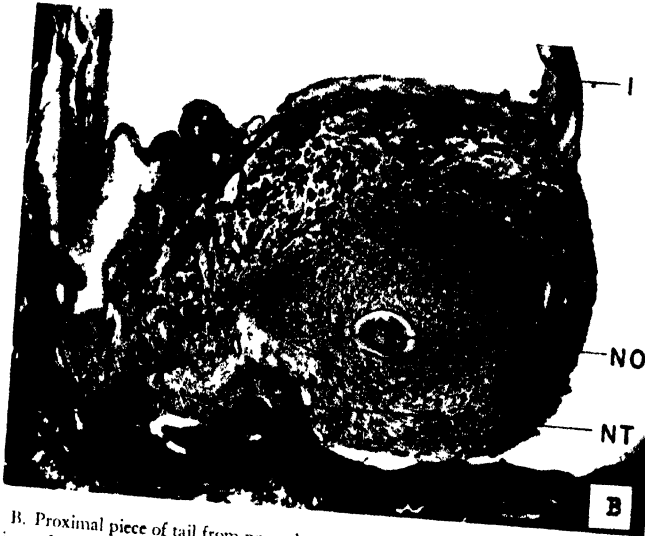
Tissue-culture experiments. Before concluding that the effect of gene *d* is limited to the epidermis, it is necessary to exclude the possibility that the gene has some direct action intrinsic to the chromatophores. Several series of tissue cultures were prepared from embryos of both genotypes, involving in all over 300 explantations from the posterior trunk region of early neurulae to hanging drops in Holtfreter's solution. All tissue cultures were maintained in a constant-temperature room



Proximal piece of tail from 11 day *Kt* embryo from mating *Kt* \times *Kt* 4 days in host
NT neural tube, *NO* notochord, *S* somite, *G* gut, *I* iris $\times 200$



A. Tail bud of 9-day embryo from mating normal \times *Ki*. Dorsal piece of tail bud only, mostly neural plate. 4 days in host. $\times 200$.



B. Proximal piece of tail from normal 11-day embryo from mating *Ki* \times *Ki*. Ventral piece of tail, containing right somite and piece of notochord. 5 days in host. $\times 200$.

• Abbreviations as in plate 3

at 20° C. Melanophores of both genotypes are capable of pigment production *in vitro*, with no discernible differences between the two groups in rate or degree of pigmentation of the cells. This result was unexpected, since some diffusible substance from the epidermis was thought to be essential to melanin synthesis in the axolotl, and the melanophores on the cover glasses were not in association with epidermis. The same result was obtained in explants

to distinguish between mesenchyme cells and pro-pigment cells, some of the counts may have represented the former cell type, although it could be seen in the older cultures that the population of migrating cells on the glass was composed almost exclusively of chromatophores. The mitotic rates of the cells observed exhibited a decline from about 6 per cent at 3 days to almost zero at 8 days, mitoses being practically negligible after that time (table

TABLE 6
MITOSES IN TISSUE CULTURES FROM AXOLOTL NEURAL CREST

AGF (days)	WHITE AXOLOTL			BLACK AXOLOTL		
	Total cells	Mitotic cells	Per cent mitosis	Total cells	Mitotic cells	Per cent mitosis
3	1263	84	6.6	626	25	4.0
4	991	58	5.9	494	13	2.6
5	912	39	4.3	580	20	3.5
6	1951	63	3.2	980	17	1.7
7	1134	28	2.5	763	5	0.7
8	1208	6	0.5	203	0	0.0
10	732	4	0.5	550	4	0.7
14	1674	4	0.2	706	2	0.3
18	1347	8	0.6	84	0	0.0
21	645	0	0.0	51	0	0.0

of later series from different batches of eggs.

The studies were extended to include observations on mitotic rates and on cell migration. Samples from a series of 63 tissue cultures were fixed and stained in aceto-orcein on successive days, beginning with the third day after explantation, in order to determine whether there is any difference in inherent capacity for proliferation of cells from the two strains. The counts included only such cells of the explants as migrated out onto the cover glasses, exclusive of sheets of epithelial cells that occurred occasionally among the cultures. Since it is impossible

6). The figures for cultures of the black strain are slightly lower than those for the white strain, but not significantly so ($P < 0.20$, > 0.10). In relating these findings to conditions in the embryo, it must be remembered that the tissue-culture medium is composed only of inorganic salts and provides no nutrients to the cells, which consequently are limited to the food reserves present within them at the time of explantation. When the yolk platelets are exhausted, growth and proliferation must necessarily cease. Since, however, the larval pigment pattern is established in control embryos during the same time in which cells of the tissue cultures migrate

and produce pigment in apparently healthy condition, it seems reasonable to expect that if intrinsic differences in capacity for mitosis existed between chromatophores of the two genotypes, and were important in the development of the genetic patterns, they would show up in the mitotic rates observed. The conclusion is that potential and differentiating chromatophores of the two genotypes do not differ in mitotic capacity when isolated from the embryo.

To obtain a measure of migratory activity, the following procedure was applied to the same series of tissue cultures stained

emerge as salient features: Considerable variance was exhibited by all groups into which the data were broken down. As a summary of the genotypic group characteristics, the mean values of tissue-culture measurements of area per culture, number of cells per culture, and cell density are presented in table 7. The average values for the white group are higher than the corresponding figures for the black group. The group mean difference between area measurements is not significant, but there appears to be little doubt that there is a real difference in number of cells per cul-

TABLE 7
MEAN VALUES OF TISSUE-CULTURE MEASUREMENTS

	White (35 cultures)	Black (23 cultures)	<i>t</i>	P*
mm. ² /culture	2.211 ± 0.131	1.824 ± 0.121	2.18	>0.05
Cells/culture.	333 ± 21.7	215 ± 25.3	3.58	<0.01
Cells/mm. ²	157 ± 9.13	126 ± 11.5	2.13	<0.05

* Approximation to 5 per cent and 1 per cent level computed as mean of *t* values for d.f. 35 and 23 weighted by the two variances.

with aceto-orcein. Camera lucida drawings were made of the areas occupied by migrating cells on the cover glass. These were measured with a planimeter, and the figures converted to square millimeters. The cell density of each culture was computed by dividing the total cell counts made in the mitosis survey by the area measurements. Interpretation of results must take into account the fact that chromatophores in the cultures frequently migrated on both the glass surface and the drop surface, but that all measurements of areas occupied include only the former because cells on the drop surface floated away during fixation. All figures for the black and white groups of tissue cultures were subjected to extensive statistical analysis, from which the following points

emerge, since $P < 0.01$. The difference in density measurements is probably also significant ($P < 0.05$), but this might be expected, since these figures are derived from the cell counts, and the number of cells per culture is correlated with the cell density ($r = 0.736$ and 0.555 , for the black and white series respectively). It was possible to check on the significance of two operative variables, size of explant and age of donor, which might conceivably affect the group comparisons, because the black series contained some explants of small size (one-half and one-third of posterior trunk neural fold) as well as pieces of entire posterior trunk fold such as were used exclusively in the white series, whereas the white series contained some explants from donors with open neural folds (stage

16) as well as some from donors with closed neural folds (stage 20-21), which were used exclusively in the black series. When the data were broken down within a single genotype into two groups, on the basis of either size of explant or age of donor, there was no significant difference between the groups, a fact which indicates that the black and white genotype group differences were not due to these two experimental variables.

Further information on the history of migrating cells in the tissue cultures was obtained by averaging the figures for each day of age and plotting the values against time. The number of cells per culture and the cell density, in both black and white groups, became less with time. The area per culture, however, diminished in the black but increased in the white group. This difference may indicate a greater capacity for migration in cells from white explants as compared with black, but it may also reflect the significantly larger number of cells in the white cultures, since number of cells is correlated with area occupied ($r=0.554$ and 0.540 , for black and white respectively). Since the group mean differences between black and white with respect to area occupied are not significant, the evidence at present does not justify the conclusion that the two genotypes exhibit any real difference in migratory capacity of the chromatophores in vitro.

Samples from another series of 63 tissue cultures were fixed in Carr.ys fluid on successive days after the third day following explantation, for detailed study of the morphology of chromatophores and of the structure and history of pigment granules. This study is still in progress, but observations so far completed fail to show any differences that might be correlated with the two genes under investigation.

In summarizing the tissue-culture ex-

periments, it may be said that the study of white and black axolotl chromatophores in vitro has shown that the genes *D* and *d* do not affect the chromatophores themselves in such a way that intrinsic differences in capacity for proliferation, migration, or pigment synthesis are demonstrable in tissue cultures of the two strains. The effects of the genes in question, therefore, appear to be mediated through factors extrinsic to the chromatophores. Evidence about the nature of this extrinsic effect on pigment development has been obtained by embryonic transplantation experiments.

Transplantation experiments. Relations between developing chromatophores and their surrounding tissues were tested by embryonic transplantations, which arranged these components of the two genotypes in different combinations. Early experiments were aimed at demonstrating differences in development of chromatophores of the same origin when in association with tissues of the black strain and of the white strain. Neural folds from the posterior trunk region of early neurulae were transplanted to the mid-ventral belly region of late neurula or early tail-bud hosts. This transplantation site was chosen to eliminate any confusion of graft chromatophores with those of the host, since the ventral belly region does not become pigmented in either strain during the period of observation of this experiment. Each donor provided one transplant in a black host and one in a white host, allowing subsequent comparison of graft chromatophores of identical genotype and age developing in the two environments. Melanophores from these grafts of both genotypes exhibited no disadvantages for melanin synthesis in association with tissues of white embryos. Both types of host permitted the differentiation of completely black melanophores. The same result was obtained when neural crest from tail-bud

embryos of both genotypes was transplanted reciprocally to the normal topographic position for this tissue. On the basis of the mechanism of gene action suggested in the literature, one would expect melanin synthesis to be inhibited in the white hosts. The evidence of these experiments, therefore, does not support this view, since there appeared to be no difference in rate or extent of pigment formation by grafted cells in the two strains.

Comparison of the extent of migration of melanophores in the two types of host, on the other hand, revealed a striking difference. Melanophores of both genotypes appeared to migrate freely beneath epidermis of the black strain but not beneath epidermis of the white strain. Evidence of this inhibitory effect on migration by white tissues appeared in both heterotopic and homotopic grafts. The neural-fold pieces grafted heterotopically into the belly region adhered both to the skin and to the gut surface, and in all cases melanophores migrated into both these regions. The areas occupied by graft chromatophores in both skin and gut were measured by means of camera lucida drawings and a planimeter. When total counts of melanophores from each graft were made and divided by the area measurements, it was apparent that the pigment cells of both genotypes developing in white hosts not only occupied much less area than cells from the same donors developing in black hosts, but also were much more closely crowded together, as if they had failed to spread to a comparable degree.

When neural crest is grafted homotopically from black to white tail-bud embryos, the epidermis lying dorsal to the neural crest is necessarily included in the graft. On the white hosts this bit of dorsal epidermis formed later a section of the dorsal fin above the grafted neural crest.

In all cases melanophores migrated extensively into this section of the fin but not into adjacent areas of host fin. Another set of operations was made in two steps, in order to obtain graft melanophores of black origin growing in the complete absence of any donor epidermis. First, pieces of dorsal epidermis overlying the neural crest of black embryos were replaced by pieces of flank epidermis from white embryos. Flank, rather than dorsal, epidermis was chosen to prevent the possibility of transplanting any adhering neural-crest cells. On the following day, the black neural crests, covered now by white epidermis, were transplanted to white embryos. In these cases, melanophores did not migrate into the skin dorsal to the grafts, but dense black lines of melanophores appeared beneath the epidermis at the edge of the graft regions. Corresponding results of grafting neural crest of white embryos to black hosts under similar conditions also suggest that the mobility of pro-pigment cells is greater in an environment of *DD* (black) tissue than in one of *dd* (white) tissue.

The view that a diffusible substance necessary for melanin synthesis is provided by black epidermis but lacking in white epidermis was based on the assumption that pro-pigment cells in white embryos migrate extensively onto the flank but do not form pigment. The following experiment was designed to investigate the validity of this assumption. Triangular pieces of epidermis were transplanted from black to white embryos, some transplants being oriented with the base dorsal and some with the apex dorsal. If epidermis from a pigmented strain permits pigment formation on a white axolotl by furnishing favorable conditions for melanization to cells normally occurring on the host flank but not normally pigmented under white epidermis, then the orientation of the

grafted triangles, provided they covered the same level of flank, would make no difference in the number of melanophores appearing beneath them. If, on the other hand, the pigment cells observed under grafted black epidermis owe their position on the flank to the removal of migratory inhibition normally encountered with the host epidermis, then triangles with the base up would be available for migration to pro-pigment cells from the length of neural crest covered by the base of the triangle, whereas triangles with the apex up would be available for migration to cells from a much more restricted length of neural crest. These conditions would be reflected in different densities of melanophores beneath grafts of the two types. The process of graft healing and subsequent growth of the embryos rotated some of the triangles, so that some were later not precisely oriented with base or apex up. As a measure of the avenue open to migrating cells moving into the graft area, the ratio of the top length of the graft to the area of the graft was chosen. Graft areas, as indicated later by the distribution of melanophores, were measured by means of camera lucida drawings and planimeter, and melanophores appearing beneath the entire epidermis of the graft were counted. When the density of melanophores was plotted against the ratio of top length to area of the epidermis grafts, there was indicated an obvious correlation, as shown in figure 5.

The results of all experiments support the idea that in the white and black strains of the axolotl, the genetic differences in pigmentation are mediated through differences in the tissue environment and not in the chromatophores themselves, the white pattern resulting from an inhibitory effect concerned, not with conditions for melanin synthesis, but with the migration of pro-pigment cells.

INVESTIGATIONS ON AN ENZYME SYSTEM OXIDIZING TRYPTOPHANE TO KYNURENIN

In *Ephesia*, the gene *a* inhibits the oxidation of tryptophane to kynurenin. Attempts to demonstrate an enzyme catalyzing this activity in *Ephesia* homogenates have been essentially negative. It was therefore decided to study this enzyme system in mouse liver.

Homogenates of mouse liver were prepared by grinding in 0.1 molar phosphate

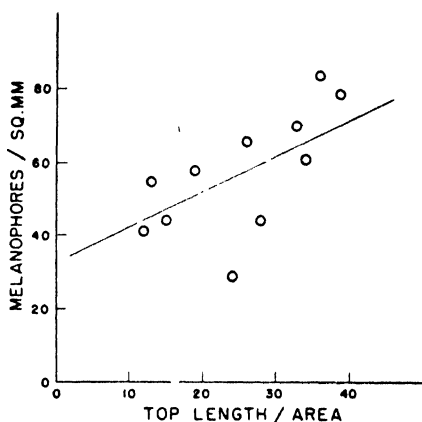


FIG. 5. Regression of melanophore density on ratio of top length to area in epidermis grafts.

buffer, pH 6.8, at 0° C. in Potter Elvehjem homogenizers. The oxygen uptake of homogenates in the presence and absence of tryptophane was determined in a Warburg apparatus at 37° C. At the end of each experiment, tryptophane was determined by the method of Bates, and kynurenin by the method of Otani and Nishino. For each experiment, therefore, there are three sets of data to establish the activity of the enzyme.

With this method it has been shown that oxidation of tryptophane to kynurenin does occur in mouse-liver homogenates. The enzyme concerned seems to be present in

low concentration, since 50 per cent homogenates are necessary to obtain strong activity. Twenty per cent homogenates gave only 3 per cent of the activity of 50 per cent homogenates, and no activity could be detected in 10 per cent homogenates.

Some properties of the enzyme system were studied in 50 per cent homogenates. Its optimum pH is between 6.7 and 7.1. It loses activity on standing, so that after two days at 0° C. only 65 to 70 per cent activity is left. Dialysis against water at 0° C. for 16 hours does not affect the activity. The enzyme system was found in liver only; 50 per cent homogenates of mouse lung, kidney, spleen, and testicles were inactive.

When liver homogenate is centrifuged, activity is found both in the sediment and in the supernatant. After centrifuging for one hour at 18,000 r.p.m., 55 per cent of the original activity is found in the supernatant. After fractionated precipitation with $(\text{NH}_4)_2\text{SO}_4$ and subsequent dialysis against water for 16 hours at 0° C., all activity is found in the fraction precipitated at one-third saturation with $(\text{NH}_4)_2\text{SO}_4$. Globulins prepared in this way oxidize tryptophane to kynurenin at an optimum pH of 6.8 to 7.0. The oxygen-consumption curve is characterized by a lag period after addition of tryptophane, during which no increased oxygen uptake occurs. This lag period lasts from 20 to 40 minutes. The need for cofactors is demonstrated by the fact that the activity of these preparations is considerably increased by addition of Mg^{++} ions and of a Kochsaft prepared from mouse liver. During the reaction, CO_2 is released.

These experiments have suggested two possible reasons for the failure of *Ephestia* homogenates to show oxidation of tryptophane to kynurenin. An inhibitory effect of *Ephestia* homogenates on mouse-liver

homogenates was described in Year Book No. 47. Evidence obtained recently indicates that slight activity may be present in the globulin fraction obtained from *Ephestia* pupae, but not in that obtained from larvae. This would indicate that the enzyme system may be more concentrated in pupae than in larvae, in agreement with the fact that most of the pigment production takes place in the pupal stage.

Serological differences between a^+ and a Ephestia. Evidence was reported last year that the gene *a*, besides affecting pigment metabolism, also causes the formation of qualitatively different proteins. This assumption has been further investigated by serological methods. Rabbits were immunized by five subcutaneous injections at 6-day intervals with 0.9 per cent NaCl extracts from homogenized *Ephestia* larvae. Three rabbits were immunized against a^+a^+ and two received extracts from larvae of an *aa* strain that had been made isogenic with the a^+a^+ strain by outcrossing for 8 to 9 generations. Seven days after the last injection, the rabbits were bled and the serum obtained.

The sera were tested against antigens from both strains by means of the precipitin reaction. The antigens used in this case were cleared by centrifugation at 12,000 r.p.m. for 1 hour. The supernatant was of a clear greenish color, but had a tendency to form a black precipitate on standing. The antigens were therefore used immediately after being prepared, and compared on the basis of their nitrogen content, which was determined by a micro-Kjeldahl procedure.

No differences in the reaction of the sera against homologous and against heterologous antigens were found by simple dilution. Three of the sera that had relatively high titers (between 1/10,000 and 1/100,000) were more thoroughly tested by the optimum flocculation method. Dif-

ferent dilutions of antigen were mixed with a constant dilution of serum, and the time of the first appearance of visible flocculation was determined for each tube. The ratio of serum to antigen in the tube showing fastest flocculation was designated as optimal proportion. In table 8 the optimum proportion for the sera tested is expressed as milligrams of antigen nitrogen per cubic centimeter of antiserum. The numbers in parentheses indicate the number of determinations performed.

TABLE 8

OPTIMUM PROPORTIONS FOR THREE ANTI-EPHESTIA RABBIT SERA WITH THE HOMOLOGOUS AND HETEROLOGOUS ANTIGENS

(Optimum proportion expressed as milligrams antigen N reacting optimally with 1 cc. of serum)

Serum	Antigen	
	<i>a'a'</i>	<i>aa</i>
1 (anti- <i>a+a'</i>).	0.282 (3)	0.379 (4)
3 (anti- <i>a'a'</i>).	0.280 (4)	0.379 (3)
6 (anti- <i>aa</i>).	0.206 (3)	0.138 (2)

The table indicates that in every case the sera showed a higher titer when tested with the homologous than when tested with the heterologous antigen. In repeated determinations, some variability of the optimum proportion values, expressed in milligrams N, was found; but in not a single case did the ranges for the heterologous and the homologous antigens overlap.

The sera were absorbed with the heterologous antigen by incubating antigen and serum at optimum proportions for 1 hour at 37° C. and leaving in the cold for 24 hours. After centrifugation, the supernatant sera were tested against the homologous and heterologous antigens. Sera 1 and 6 still gave reactions with both anti-

gens after absorption, but higher titers with the homologous than with the heterologous antigen. After a second absorption, these two sera did not react with either antigen.

Serum 3, on the other hand, lost its ability to form a precipitate with the heterologous *aa* antigen after one absorption at optimum proportions. It still reacted with the homologous *a'a'* antigen in a 1:25 dilution (0.0055 mg. N). This absorbed serum, which formed a specific precipitate with *a'a'* antigen, was used to determine the chemical nature of the active antigen. Antigen fractions were obtained from both *a'a'* and *aa* saline extracts, by half and full saturation with $(\text{NH}_4)_2\text{SO}_4$ and subsequent dialysis against H_2O . The serum gave a precipitate only with the fraction obtained by half saturation of *a'a'* extract with $(\text{NH}_4)_2\text{SO}_4$. All other preparations failed to react.

These experiments demonstrate that antigenic differences exist between *a'a'* and *aa* *Ephestia*. They furthermore indicate that at least one of the substances responsible for these differences is a protein belonging to the globulin fraction.

SEROLOGICAL STUDIES WITH THE BRACHYURY MOUSE

The positive finding of serological differences between *a'* and *a* *Ephestia* suggested the possibility that similar serological differences might be found for mouse genes. The gene *T* (Brachyury) was used. Testicles and spleens from freshly killed *T/+* mice were ground up in physiological saline and extracted three times with saline in the cold. The pooled extracts were injected into rabbits. Five subcutaneous injections were made at 6-day intervals. Sera were obtained on the tenth day after the last injection. The sera were then tested against antigens obtained from

males of the genetic constitutions $T/+$ and $+/+$, which had been made isogenic by outcrossing for 18 generations. Two different antigens were used: the first saline extract, and a second saline extract obtained by treatment with saline of the sediment from the first extraction. It is assumed that the first extract contained easily soluble proteins, including the serum proteins from the blood left in the organs, whereas the second extract contained substances that dissolved with more difficulty, probably including small particles. These two types of antigen were prepared from both testes and spleens of both strains, and kept at 0° C. after preservation with merthiolate 1/10,000. Their nitrogen content was determined, and they were adjusted to contain equal amounts of nitrogen.

In precipitation tests the sera did not show any differences in titer when tested with the homologous and heterologous antigens. Absorption experiments with the first antigen of the $+/+$ strain were unsuccessful, except in the case of one anti-spleen serum, which reacted with the homologous antigen. After absorption with the second antigen of the heterologous strain, three sera (two against testicles, one against spleen) turned out to give precipitates with the homologous but not with the heterologous antigen. Serological differences between $T/+$ and $+/+$ animals are therefore clearly indicated.

Serological differences between $T/+$ and $+/+$ testes were also demonstrated by complement fixation. The same sera were used as for the precipitation tests, after inactivation for 30 minutes at 56° C. The antigens were adjusted to contain 0.05 mg. N. Different dilutions of sera were used, and incubated in the presence of complement (2 units) for 30 hours at 37° C., and for 30 minutes at room temperature. At the end of this period, the

indicator system, consisting of 2.5 per cent sheep erythrocytes and 2 units of hemolysin, was added, the tubes were incubated for 30 minutes at 37° C., and the degree of hemolysis was recorded. The tubes were then kept for 24 hours in the refrigerator. At the end of this period, the tubes were centrifuged, the supernatant discarded, and the sedimented blood corpuscles suspended in 5 cc. of 0.9 per cent saline. The saline suspension was then read in the Klett-Summerson colorimeter with a blue filter. The degree of lysis was recorded in terms of the percentage of red blood corpuscles found as compared with the saline control.

The results of one of these experiments are recorded in figure 6. The curves obtained in this way for the second antigen from $+/+$ and from $T/+$ are obviously different, the serum reacting more strongly with the homologous than with the heterologous antigen. This is apparent not only from the titer for complete lysis, but particularly from the general shape of the curves. More complement appears consistently to be fixed by $T/+$ antigen than by $+/+$ antigen at the same serum dilutions. The same result has been obtained with two other anti- T testicle sera, tested with the second antigen. On the other hand, no differences were found in the same sera when they were treated with the first saline extracts of $T/+$ and $+/+$ testicles.

The anti- T testicle sera were also tested against antigens obtained from $Ki/+$ animals. Ki is a gene situated close to T on the same chromosome, having similar though not identical phenotypic effects. It appears from the curve of figure 6 that $Ki/+$ is intermediate between $T/+$ and $+/+$. This result is also evident in the other two anti- $T/+$ testicle sera tested. It therefore appears that connected with the gene Ki there is an antigenic structure similar to but not identical with T . The

results of the experiments with *Ki* antigens seem to indicate a physiological relation between the closely linked genes *T* and *Ki*.

Absorbed sera proved to be highly anti-complementary when tested by means of the complement-fixation method.

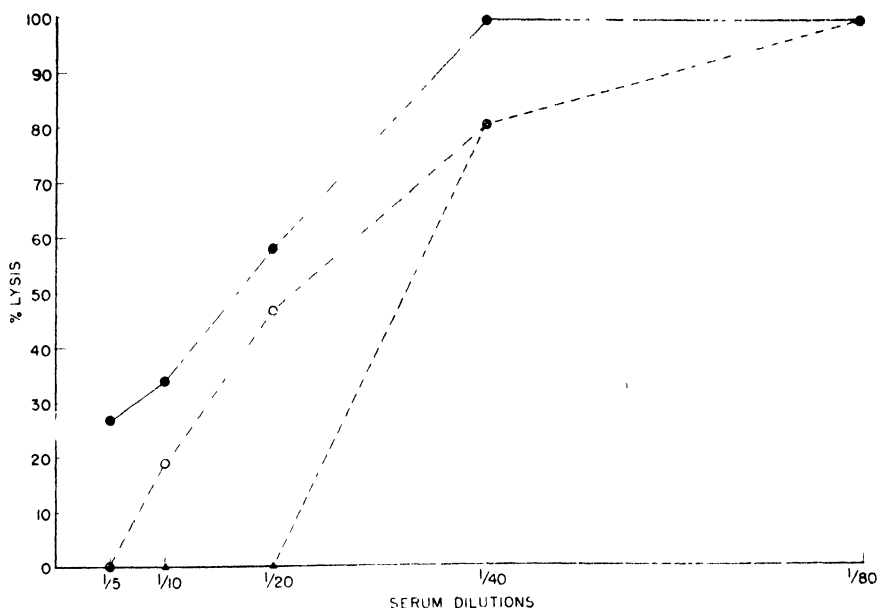


FIG. 6. Complement fixation of an anti *T* testicle serum with "T" and "Ki" antigens from *T*, *+*, and *Ki* testicle antigens, adjusted to contain 0.05 mg N each. Abscissa: serum dilutions. Ordinate: per cent hemolysis, determined by nephelometric measurement of nonhemolyzed corpuscles.

●—● = *++*; Δ---Δ = *T/+*; ○---○ = *Ki/+*.

GENETIC STRUCTURE OF NATURAL POPULATIONS

TH. DOBZHANSKY, *Columbia University, New York, and University of São Paulo, Brazil*

Most biologists agree that mutation to the environment is the principal driving force of organic evolution. But modern genetic thought visualizes the relations between organism and environment in a way quite different from environmentalistic theories of the nineteenth century, which have recently become a topic of renewed discussion because of the polemics aroused by Lysenko and his partisans. Living beings are not passively molded by physical agencies, as mechano-Lamarckists believed. Nor can a species change by exertion of its

will, as supposed by psycho-Lamarckists and finalists. Moreover, organisms are not altered by a kind of sympathetic magic, which makes them able to "select" useful and to reject useless materials from changed environments, as imagined by Lysenko. It is the view of a majority of evolutionists that mutation and Mendelian recombination continually produce innumerable genetic materials, some of which are more and others less suitable for perpetuation in various environments. The available genotypes are then adjusted by

natural selection to the opportunities available in the world.

To say that evolution is brought about because organisms are changed by environment is inexact. Organisms change in the process of becoming better able to survive and reproduce in the environments in which they live. Evolution is a response of the organism to the challenge of the environment. And this challenge does not arise from physical conditions alone, but also from interactions with other organisms that share the same physical environment. It is probable, at least in higher organisms, that the biotic environment is more important in evolution than are physical conditions in the narrow sense.

CO-OPERATIVE STUDIES ON TROPICAL DROSOPHILAS

The above conception of the relations between environment and evolution suggests new types of study. Genetic experiments are done mostly with domestic animals, cultivated plants, or species otherwise associated with man, such as commensals, weeds, or pests. Many organisms domesticated by or living with man have important technical advantages for use as experimental materials. But to understand the evolutionary process as a whole, work on such species is not sufficient. We must examine the causal links connecting the evolutionary patterns of different organisms with the biota of which these organisms are constituent parts. Interrelationships between living beings and the main types of environment that exist on our planet are to be studied.

Comparison of genetic population structure in related species living in temperate and in tropical climates seems especially promising. In any temperate or cold climate, sharp seasonal changes in the environment occur every year. Any popula-

tion of organisms living under such conditions must evidently be adapted to cope with a succession of sharply different environments. Tropical climates in general permit the environment to remain relatively more uniform throughout the year, and may seem to demand less adaptive versatility from the inhabitants. Tropical biota, however, include greater numbers of animal and plant species than is the case in temperate or cold lands. Thus members of tropical biotic communities meet a great variety of challenges, to which they may respond by adaptive evolutionary changes. The evolutionary process in the tropics, taken as a whole, may have a faster tempo and a greater creativeness than in temperate and cold climates.

A program of comparative studies on population genetics of species of *Drosophila* in temperate and in tropical climates was initiated some seven years ago (see Year Books Nos. 43, 1943-1944, and 47, 1947-1948). In 1943, the writer, in co-operation with Dr. C. Pavan, of the University of São Paulo, made an exploratory survey of species of *Drosophila* that occur in the state of São Paulo and near Belem in the state of Pará in Brazil. Two species, *Drosophila willistoni* and *Drosophila prosaltans*, were chosen as materials for further and more intensive study. The former is the commonest species in most of Brazil; it is also ecologically most versatile, since it occurs in a great variety of environments and feeds on many species of fruits. In contrast, *D. prosaltans* is a rare form, ecologically specialized; thus far it has been found in large numbers only in a few localities, in the state of Maranhão and on the island of Marajó. Preliminary genetical work on these species, necessary to make them available for experimental studies of the genetic population structure, has been carried out at Columbia University by Mr. B. Spassky, Mr. S. Zimmering, Pro-

fessor A. G. L. Cavalcanti, and the writer.

From August 1948 to June 1949, inclusive, a group of investigators, assembled at the laboratory of Professor André Dreyfus, at the University of São Paulo, carried out a program of orientation studies on population genetics and ecology of tropical species of *Drosophila*, especially *D. willistoni* and *D. prosaltans*. The group included, besides Professor Dreyfus, Drs. C. Pavan, A. Brito da Cunha, and E. Nascimento Pereira, of the University of São Paulo; Professor A. G. L. Cavalcanti and Miss Ch. Malogolowkin, of the University of Brazil, Rio de Janeiro; Dr. A. R. Cordeiro, of the University of Porto Alegre, Rio Grande do Sul; Ing. Agr. M. Wedel, of the University of Buenos Aires, Argentina; Dr. Hans Burla, of the University of Zürich, Switzerland; Mrs. N. Dobzhansky, and the writer. Mr. B. Spassky remained at Columbia University in New York, but participated in the co-operative program by furnishing certain mutant strains and carrying out many experiments. The work of the above group was made possible by financial assistance extended by the University of São Paulo, the Carnegie Institution of Washington, and the Rockefeller Foundation. Brazilian military and civil authorities, in particular General Newton Cavalcanti, Brigadier General Eduardo Gomes, the governors and their aides in the state of Goyaz, Amazonas, Paraná, Rio Grande do Sul and the territories of Rio Branco, Acre, and Guaporé, Dr. Felisberto de Camargo, director of the Instituto Agronomico do Norte at Belem do Pará, and other officials and private persons too numerous to be named, greatly facilitated the field work by providing airplane and other transportation and by extending many valuable courtesies, which made the travel and collection in remote parts of Brazil a success as well as a pleasure.

COLLECTING JOURNEYS

The first task was to collect material for cytological studies and for genetic experimentation and to make field observations on ecology of *Drosophila* that inhabit the principal climatic and vegetational zones of Brazil. The regions in which collections were made are shown by black circles on the accompanying map (fig. 7).

Three stations were established in the state of São Paulo, at which collections were made at approximately bimonthly intervals. One of them, in coastal rain forest near Vila Atlântica, is sufficiently warm and humid throughout the year to permit the maintenance of flourishing *Drosophila* populations. The second, near Mogi das Cruzes on the plateau, has a cool and fairly dry winter season; and the third, near Pirassununga in the interior of the state, is hot and humid in summer but dry in winter. These three stations formed a climatic gradient, whose influence on *Drosophila* populations was studied.

The collecting expeditions to localities more remote from the laboratory in São Paulo were as follows. From October 29 to November 10, 1948, Dr. Pavan and the writer visited the central part of the state of Goyaz, and made collections at Monjolinho (near Anapolis) and at Palma (Paraná, see map). This is a zone of *cerrado* savanna and of gallery forest vegetation, warm throughout the year but with pronounced wet and dry seasons, the latter causing reduction of the abundance of most species of *Drosophila*. From January 5 to 26, Professor Cavalcanti and the writer collected in the vicinities of Cruzeiro do Sul and Palmares, territory of Acre, and at Porto Velho, territory of Guaporé. This is a zone of exuberant forest vegetation of Amazonian type (*hylaesa amazonica*); despite variations in the amount of precipi-

tation at different seasons, temperature and relative humidity remain continually favorable for *Drosophila* breeding. Between February 22 and March 5, Dr. Pavan and

most of the year there is almost no precipitation and the vegetation dries out and loses its foliage, as it does in winter in temperate climates. These conditions are

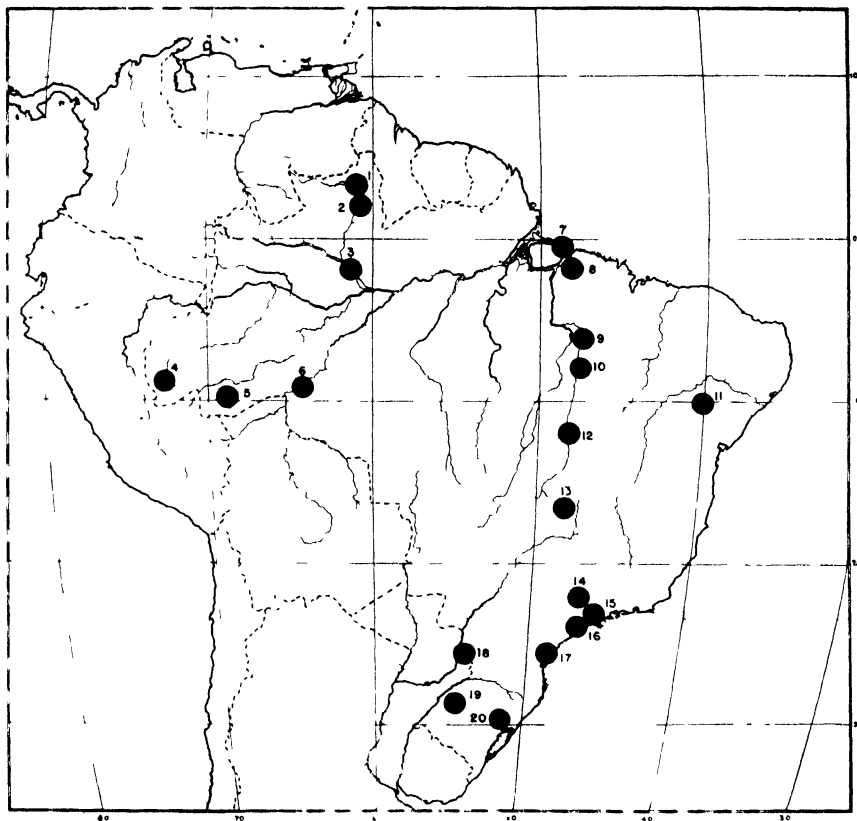


FIG. 7. Map of South America, showing the location of the places where samples of *Drosophila* populations were taken. 1, Savanna of Rio Branco; 2, Rio Mucujá, territory of Rio Branco; 3, Rio Negro, Amazonas; 4, Cruzeiro do Sul, Acre; 5, Palmares, Acre; 6, Porto Velho, territory of Guaporé; 7, Marajó Island; 8, Belem, Pará; 9, Imperatriz, Maranhão; 10, Carolina, Maranhão; 11, Catuní, Bahia; 12, Paranã (Palma), Goyaz; 13, Monjolinho, Goyaz; 14, Pirassununga, São Paulo; 15, Mogi das Cruzes, São Paulo; 16, Vila Atlantica, São Paulo; 17, Paranaguá, Paraná; 18, Iguassú National Park, Paraná; 19, Santo Angelo, Rio Grande do Sul; 20, Reuter, Rio Grande do Sul.

the writer made an excursion to Rio Salitre and to Catuní, near Bomfim in the *caatingas* in the state of Bahia. The *caatingas* are characterized by the sharpest seasonal climatic changes possible in the tropics;

close to the limit of endurance for *Drosophila*, and only a few species are able to withstand the rigors of the *caatingas*.

Dr. A. da Cunha, Mrs. Dobzhansky, and the writer visited the state of Paraná, and

made collections at Paranaguá on the Atlantic coast, and at the Iguassu National Park at the boundary with Argentina and Paraguay, between March 22 and April 2. The conditions at Paranaguá are, on the whole, similar to those at Vila Atlântica (see above). The Iguassu region has a forest of tropical aspect, but the temperatures are low in winter and frosts occur. A relatively small variety of species of *Drosophila* was encountered in the region. From May 18 to 23, Dr. Cordeiro and the writer visited the state of Rio Grande do Sul and collected at Santo Angelo in the western part of the state. Dr. Cordeiro made a collection at Reuter in the south central part at an earlier date, in January. The state of Rio Grande do Sul is outside the tropical zone and has cool winters. A rather large number of species of *Drosophila* was nevertheless encountered in the collections made in that state.

Between April 12 and May 10, Dr. Pavan and the writer collected in the savannas of the territory of Rio Branco and at the margin of the forest zone at Rio Mucajaí in the same territory, on the lower Rio Negro in the state of Amazonas, and near Belem in the state of Pará. The savanna of Rio Branco has a long dry season, and tree vegetation occurs there chiefly in the form of gallery forests along streams and near marshes. Rio Negro has coniferous rain forests and an equable hot and humid climate. Mucajaí is probably intermediate climatically. The Belem region, despite its having a drier and a wetter season, is probably as favorable for the maintenance of large *Drosophila* populations as is the Rio Negro region; and a large variety of species, many of them new to science, was encountered there. Collections were made near Belem also in September and October 1943 by Dr. Pavan and the writer, in June 1948 by Dr. Pavan, and in July–September 1949 by Dr. Pavan and the writer, so that

information was obtained about the status of *Drosophila* populations at different seasons.

From July 29 to August 13, Dr. Pavan and the writer traveled in the state of Maranhão, and collected in the vicinities of Carolina and Imperatriz. This region is transitional between the savannas (*campos cerrados*) of central Brazil and the Amazonian rain forests of Pará. Pronounced wet and dry seasons occur yearly. A gradual change in the composition of the *Drosophila* fauna was observed, from that previously found in the state of Goyaz to that living near Belem. Between August 27 and September 5, Dr. Pavan and the writer visited the estates belonging to the family Tocantins Penna in the north-eastern part of Marajó Island, state of Pará. Despite its relative proximity to Belem, this part of Marajó has extensive grass-covered swamps, alternating with rather open forests growing on higher ground; wet and dry seasons are clearly differentiated; and the *Drosophila* fauna proved to be unique because of a high frequency of *D. prosaltans*, which is rare in most other parts of Brazil. Finally, Dr. Warwick Kerr very kindly collected and sent to us a sample of the *Drosophila* population from the vicinity of Santa Cruz de la Sierra, in Bolivia, in July 1949.

The collecting journeys made from August 1948 to September 1949 in the Brazilian territory entailed between 27,000 and 28,000 kilometers of airplane travel alone. The number of *Drosophilas* of various species collected and classified during this time was close to 110,000 individuals.

DIVERSITY OF SPECIES IN TROPICAL ENVIRONMENTS

Perhaps the most striking and significant difference between *Drosophila* communities in tropical and in temperate countries

is that the former, as a rule, contain more species than the latter. For example, at Chitina, Alaska, the writer collected at least a thousand *Drosophilas*, all of which belonged to a single species, *D. athabasca*. Collection with the aid of fermenting banana bait in a favorable locality in California mountains is likely to yield, among some hundreds of individuals, only 5 to 10 species. Localities are common in which only 2 or 3 species, or even a single species, are found. Furthermore, regardless of the number of species caught, one of them, *D. pseudoobscura*, is in many localities more common than all others combined. By way of contrast, collection on banana bait in Brazilian forests usually yields more than 10 species, and may reveal more than 30 in a single neighborhood less than one square kilometer in area. Moreover, several species may be common in such collections, none of which is dominant. Only in those tropical environments that are intrinsically unfavorable for *Drosophila* does the number of species become reduced and one or two species become dominant. This occurs, for example, in the peculiar desert regions of northeastern Brazil called *caatingas*, where the heat and aridity of a prolonged dry season appear to be beyond the toleration limit of all except a few species. *Drosophila nebulosa* is the unchallenged dominant in the *caatingas*, as it is also during the dry season of the year in the savanna (*campo cerrado*) of central Goyaz.

Drosophila species that are attracted to banana bait subsist in nature mainly on fermenting fruits, tree sap, and fallen flowers, which in tropical forests often ferment on the humid and well shaded ground. For insects that feed on substances of this kind, tropical forests evidently offer more diversified and favorable conditions than do tropical savannas, or temperate—particularly cold—environments. It may

be noted, however, that many other groups of organisms likewise show greatest proliferation of species in tropical lands. Thus the astounding diversity of species of trees found growing in small areas in Brazilian forests was noticed and commented upon by the early explorers. In co-operation with Dr. George Black, of the Instituto Agronomico do Norte, and Dr. Pavan, counts were made of trees with diameters of more than 10 cm. at chest height on two one-hectare (100×100 m.) plots near Belem do Pará. One of these plots in a periodically inundated forest (*igapó*) had 60 species among 564 individual trees. The second, on higher land (*terra firme*), had 87 species among 422 trees.

Tropical environments thus contain a greater variety of ecological niches (biological opportunities) for living beings than do temperate-zone environments. To occupy an ecological niche, however, an organism must be adapted for it, that is, must possess a combination of physiological and morphological traits that make maintenance and perpetuation of life possible. Different combinations of traits are needed for efficient exploitation of different ecological niches. To conquer the ecological niches available in a given region, life must accordingly evolve a variety of genetic constitutions proportionate to the variety of biological opportunities. This can occur in two ways. First, numerous species may be formed, each adjusted to a single ecological niche or to a few similar ones. Second, a relatively small number of species may become polymorphic, that is, each composed of a variety of adaptively different genetic types. It appears that both ways have been followed in the evolution of *Drosophila*, and that a greater variety of species, and a greater polymorphism within some of these species, have evolved in the tropics than in temperate countries.

LOCAL AND SEASONAL VARIATIONS IN
RELATIVE FREQUENCIES OF
DROSOPHILA SPECIES

A community of many related species, each adapted to a slightly different set of environmental conditions, represents a sensitive system, which can be expected to react to even slight changes in the environment. *Drosophila* populations of tropical forests show this lability in several different ways. In experiments made by Burla, Brito da Cunha, Cavalcanti, Pavan, and the writer, similar bait was placed at 10-m. intervals along 200-m. transects in what appeared to be a reasonably uniform forest at Horto Florestal near São Paulo. *Drosophila* flies that came to each bait were collected separately and classified as to species. The results showed that the different species are far from being uniformly distributed over the territory sampled. Instead, nuclei of high population density are scattered through the forest, separated by areas where flies are rare or even absent. Furthermore, the localization of these nuclei is by no means the same for different species. A neighborhood that is evidently attractive for *D. willistoni* may contain few individuals of *D. griseolinata*, and vice versa. This microterritorial differentiation breaks up a community consisting of many competing species into tiny colonies with a much smaller number of competitors.

The formation of nuclei of population density for each species is caused by the fact that different species are attracted preferentially to different food substances. This can be shown if, instead of collecting *Drosophilas* on uniform bait placed at different points, one finds them on different natural baits located as close together as possible. On the ground in tropical forests one often finds fallen and fermenting fruits or flowers of one species of tree, and a short distance away fruits or flowers of

another species. Collections made on such natural baits by Pavan, da Cunha, and the writer disclosed two interesting facts. First, different species of *Drosophila* show preferences for different foods. Within a distance of some ten meters, hundreds of individuals of a *Drosophila* species may congregate on one and largely ignore another natural bait. Second, such preferences do not reach the stage of rigid dietary specialization, and a kind of fruit avoided by a species of *Drosophila* in one place may be relatively well attended in another place. Just what causes these variations in attractiveness of the same kind of fruit is not clear. Possibly some microclimatic differences between places in which the fruits happen to be located are effective, and the yeasts and other microorganisms that make the fruits ferment may well be different and may attract or repel different *Drosophilas*. However that may be, most or all species of *Drosophila* (except the fungus feeders, which we did not attempt to include in our studies) can utilize a great variety of foods, and hence are competitors in nature. The competition is alleviated, however, by different food preferences, which may permit some species to be temporary monopolists in some parts of the environment.

Seasonal changes in the environment occur in tropical forests, even in regions such as the coast of São Paulo or the equatorial rain forests near Belem do Pará, where temperature and humidity are favorable at all times for the development of plants as well as of *Drosophila*. For example, different species of trees come into flowering and fruiting at different seasons. Although such seasonal changes may seem small compared with those in temperate climates, they profoundly affect the *Drosophila* populations.

As indicated above, *Drosophilas* were

collected at approximately bimonthly intervals, chiefly by Pavan, da Cunha, Burla, and the writer, at three stations in the state of São Paulo. At each of these stations, about a dozen places were marked, so that banana bait was always placed in the same positions. The flies collected were classified as to species. The relative frequencies of various species at each collecting station changed greatly from season to season. Thus, *D. willistoni* and its sibling species *D. paulistorum* were common at all stations during the summer, at times even reaching the status of dominants; but during the cooler part of the year they became relatively less common than certain other species (*D. simulans* at Pirassununga, *D. mediostrigata* at Mogi das Cruzes, *D. capricorni* at Vila Atlântica). Distinct seasonal changes in relative frequencies of *Drosophila* species were observed also at Belém do Pará in the equatorial zone.

A problem of much interest is whether these seasonal changes are cyclic; that is, whether the same relative frequencies of the different species will recur in each locality year after year. One can well imagine that a system composed of some twenty species, ecologically rather similar and hence competing, may be so sensitive to environmental variation that climatic differences between years will make repetition of the same set of relative frequencies improbable. This problem must be settled by future observations. Thus far we possess only some data collected by Dr. Pavan in 1946 and 1947 at Mogi das Cruzes. Comparison of these earlier collections with those made in 1948-1949 at similar seasons indicates quite considerable differences in the composition of the populations. Unfortunately, the earlier collections were not made at precisely the same neighborhoods as the later ones, and hence the disturbing element of territorial variation is not excluded.

DIFFUSION RATE AND POPULATION DENSITY

The fact that uniform bait may attract quite different collections of species of *Drosophila* when placed at points only some 10 m. apart suggests that the flies do not travel over long distances, but come to bait chiefly in the immediate vicinity. This inference was checked by experiments on *D. willistoni* carried out by Burla, da Cunha, Cavalcanti, Pavan, and the writer in the vicinity of São Paulo.

The technique of such experiments, worked out previously for *D. pseudoobscura* (see Year Books Nos. 39-47), consists in releasing at some point in a natural environment a known number of flies marked by an easily recognizable but innocuous mutant trait, and then recording the numbers of marked and wild flies captured on bait placed at regular intervals at different distances from the point of release. Mathematical methods applicable to the resulting data were developed by Professor Sewall Wright, of the University of Chicago, for the experiments on *D. pseudoobscura*. Professor Wright has very kindly checked also the calculations made for *D. willistoni*.

The diffusion rates of flies in a two-dimensional environment are measured by the variance of the distribution of the marked flies in the territory around the point of their release at different times after their liberation. In *D. willistoni*, as well as in *D. pseudoobscura*, this variance increases with time much faster at high than at low temperatures. Temperatures of about 15° C. are limiting, since at lower temperatures the flies remain about stationary. But above this limit, *D. willistoni* shows migration rates of a lower order of magnitude than does *D. pseudoobscura*. In other words, *D. willistoni* is even more inclined to form semi-isolated local populations or colonies than is *D. pseudoobscura*.

The same experiments used to study the migration rates of the flies yield data from which the population densities of the wild flies in the experimental field can, granting certain assumptions, be deduced. Such deductions indicate population densities of wild *D. willistoni* between 10 and 28 flies per 100 sq. km. in the experimental fields near São Paulo. Population densities of all species of *Drosophila* in the same fields can be estimated, with less assurance than for *D. willistoni* alone, at between 60 and 139 flies per 100 sq. m. Population densities of *D. pseudoobscura* and related sibling species in California mountain forests have been estimated, during the most favorable season of the year, at from 0.4 to 10.0 flies per 100 sq. m.; and this species and its relatives are usually more abundant than all other species in the same localities. The conclusion is justified that the aggregate population densities of *Drosophila* are appreciably greater in tropical forests than in the forests of California.

CONCEALED GENETIC VARIABILITY IN THE
CHROMOSOMES OF *DROSOPHILA WILLISTONI*
AND *DROSOPHILA PROSALTANS*

Representatives of a species of *Drosophila* collected in nature are usually rather uniform in their externally visible traits. The morphology of each species appears to be fairly well stabilized, and deviations from the norm are adaptively undesirable. An exception to this rule is the fairly common and widespread Brazilian species *D. polymorpha*, which shows a very considerable variation in the color pattern of the abdomen. This case, studied in detail by da Cunha, proved to be a clear instance of balanced adaptive polymorphism. The forms having very light and very dark abdomens are homozygotes, whereas the intermediates are heterozygous for a pair of alleles of a single

gene. The heterozygotes are adaptively superior to both homozygotes (cf. discussion of chromosomal variability in the next section).

Studies made by several investigators, chiefly on European and American *D. melanogaster* and *D. pseudoobscura*, have disclosed that flies of these species found in nature are often heterozygous for various recessive mutant genes. These genes, when homozygous, cause the death of all or a part of their carriers (lethals, semi-lethals, subvitals), as well as sterility, modifications of the development rate, and various morphological abnormalities. The heterozygotes for these recessive genetic variants, however, are "normal" flies in every respect. These variants are thus concealed in heterozygous condition, and form a store of potential, rather than actually expressed, variability.

We have extended studies of the above type to the Brazilian *D. willistoni* and *D. prosaltans*. Strains have been synthesized in the laboratory, chiefly by Mr. Spassky, which have the second or third chromosomes (autosomes) "marked" by various mutant genes and inverted sections. By making appropriate crosses of flies collected in nature to these "marked" strains, it is possible to obtain, in the third filial generation, flies that carry the same wild chromosome twice (are homozygous for it). If the chromosome in question causes, when homozygous, a reduction of the viability of its carriers, certain deviations from normal Mendelian segregation ratios result in the cultures. Inspection of the homozygotes makes possible the detection of morphological abnormalities; and breeding tests show whether these homozygotes are fertile or sterile.

Drs. Pavan, Malogolowkin, Cordeiro, and Wedel, Mrs. Dobzhansky, Mr. Spassky assisted by Mrs. Spassky, and the writer carried out analyses of the second and

third chromosomes in population samples of *D. willistoni* collected in various parts of Brazil. Professor Cavalcanti took charge of experiments of a similar nature with *D. prosaltans*, which, being a rare species, was found mostly as isolated individuals. The results of these rather large-scale and very laborious experiments cannot be reported yet. One can state, however, that the store of concealed genetic variability found in the natural populations of the two above-named species in Brazil is at least as great as it is in the temperate-zone species studied previously. Genetic variants of diverse kinds have been encountered.

CHROMOSOMAL VARIABILITY IN *DROSOPHILA WILLISTONI*

Contrasted with the constancy of external traits in natural populations of most species of *Drosophila* is the great variability of structure of their chromosomes. This variability consists chiefly in inversions of chromosome segments. Individuals having two chromosomes of a pair with like gene arrangements (inversion homozygotes) and with unlike arrangements (inversion heterozygotes) are encountered in nature. Flies of the same species carrying chromosomes of different types interbreed at random. Experiments and observations made on *D. pseudoobscura* have shown that the chromosomal polymorphism is adaptive and that it is balanced (see Year Books Nos. 40-47). Inversion heterozygotes, with a single known exception, have adaptive values higher than homozygotes. This being the case, natural selection maintains the polymorphism in natural populations, and yet permits these populations to react by rapid alteration of their genetic composition to even small and temporary changes in the environment. Chromosomal polymor-

phism is, consequently, a part of the actual rather than of potential variability, even though this variability happens to find its expression, in *Drosophila*, in physiological rather than in visible morphological traits.

Samples of natural populations of *D. willistoni* from different parts of Brazil were brought to the laboratory at São Paulo, and the larval salivary-gland chromosomes were studied in their offspring by da Cunha, Burla, and the writer. A chromosomal polymorphism more extensive than that known in any other species of *Drosophila* was disclosed. Inversions were found in all the chromosomes—the autosomes as well as the sex chromosomes. At least 34 different inversions were encountered (as compared with 20 in *D. pseudoobscura*, chromosomally the most variable species hitherto known, in which 15 of the inversions are concentrated in a single chromosome, the third). Taking the Brazilian populations as a whole, individuals that carry no inversions (inversion homozygotes) are definitely less common in nature than are inversion heterozygotes. One of the larvae examined was heterozygous for 16 inversions, which seems to be the highest degree of inversion heterozygosis found thus far in any organism.

Although there is no direct proof that the chromosome polymorphism in *D. willistoni* is balanced and adaptive, this may be accepted as the most likely working hypothesis, by analogy with other species studied in this respect. Chromosomal polymorphism may be regarded, then, as a means whereby the species becomes capable of occupying and exploiting efficiently a variety of ecological niches in the environment in which it lives. The amount of this polymorphism in populations that inhabit different climatic regions of Brazil becomes an interesting problem for study, and efforts have been made to approach the problem from several angles. The re-

sults are not ready to be reported in detail. One fact is clear enough, however; namely, that inversion heterozygosis is more frequent in some parts of Brazil than in others. Thus far, the minimal value was observed in a sample from the *caatingas* in the state of Bahia, where the average number of inversions carried by an individual in the heterozygous state is about 0.8. The maximal value, about 9 heterozygous inversions per individual, occurred in samples from the savanna-gallery forest region of central Goyaz. A high degree of inversion heterozygosis was found also in samples from the tropical rain forests of Acre, Guaporé, and Rio Negro, whereas the rain forests near Belem do Pará have relatively few inversion heterozygotes.

COMPARISON OF CHROMOSOMAL VARIABILITY IN DIFFERENT SPECIES

Drosophila willistoni is the commonest species of the genus *Drosophila* in many parts of Brazil. Collection on different natural baits (see above) showed that this species is also very versatile ecologically, in the sense that it is found on a great variety of foods. It is tempting to correlate these facts with the great amount of chromosomal polymorphism present in the species; and in this connection it is logical to inquire whether, in other species of *Drosophila* that are ecologically less versatile and less common than *D. willistoni*, chromosomal polymorphism is proportionately less. A study of chromosomes was accordingly undertaken, by Professor Dreyfus on *D. nebulosa*, by Professor Cavalcanti on *D. prosaltans*, by Miss Pereira on *D. sturtevantii*, by Dr. Burla on *D. annulimana* and related forms, and by da Cunha, Burla, Pavan, and the writer on *D. paulistorum*, *D. equinoxialis*, *D. tropicalis*, and other species. The work has not been completed yet, but it is safe to say that no

other species so far studied approaches *D. willistoni* in frequency of inversion heterozygosis.

Comparison of *D. willistoni*, *D. paulistorum*, *D. equinoxialis*, and *D. tropicalis* is particularly instructive. These species are very closely related and are morphologically almost indistinguishable (see below). *D. willistoni* has the widest geographical distribution: it extends from central Mexico and the southern tip of Florida, southward to at least the Rio Grande do Sul in Brazil and the territory of Misiones in Argentina. As stated above, it is in many places the commonest species of *Drosophila*, and it shows the greatest chromosomal polymorphism. *D. paulistorum* has a somewhat narrower distribution: it is known from equatorial Brazil (territory of Rio Branco, state of Pará) down to the coast of São Paulo and Paraná. Within this distribution region it competes in commonness with *D. willistoni* and is, in fact, more numerous than the latter in some places (Belem do Pará) or in some seasons (in summer on the coast of São Paulo). Its chromosomes show a variety of inversions second only to that in *D. willistoni*; the average number of heterozygous inversions per individual, although varying from region to region, is fairly high. *Drosophila equinoxialis* and *D. tropicalis* are thus far known to occur only in the basins of the Amazon and the Tocantins—from Belem do Pará to Rio Branco and Rio Negro, and from central Goyaz to Guaporé and Acre. Not only are the distribution regions of these species included among those of *D. willistoni* and *D. paulistorum*, but even where *D. equinoxialis* and *D. tropicalis* do occur they have rarely been found to be as abundant as their rivals. Only a few inversions have been observed in *D. equinoxialis* and *D. tropicalis*, and the fre-

quency of heterozygous inversions per individual is distinctly low.

SIBLING SPECIES

Mass collecting of *Drosophilas* in different parts of Brazil led, as was to be expected in a tropical land whose *Drosophila* fauna had been only superficially studied, to the finding of many new species. Unfortunately, our program of research left little time for strictly taxonomic work. Some taxonomic situations had to be straightened out, however, before other types of work could proceed. One such situation arose with the discovery that the flies originally classified as *D. willistoni* actually belong to four distinct species, which are very similar in morphological traits. Following Mayr, such morphologically similar species are called sibling species. Burla, da Cunha, Cordeiro, Malogolowkin, Pavan, and the writer submitted the four sibling species of the *willistoni* group to a comparative morphological, genetic, and cytological analysis.

The four species, *D. willistoni*, *D. paulistorum*, *D. equinoxialis*, and *D. tropicalis*, are reproductively isolated populations, which cannot exchange genes with one another. If females of any one of these species are kept with males of any of the other three, few or none of the females are inseminated. This sexual isolation is relatively weaker when *D. paulistorum* males are used; that is, *D. paulistorum* males are accepted more readily by females of the other species than are other hetero-specific males. Regardless of whether or not some interspecific matings occur, however, no hybrid offspring are produced.

Whether this is due to early death of the hybrid progeny or to failure of the hetero-specific sperm to consummate fertilization is not known. In any case, the reproductive isolation is complete.

Apart from crossing experiments, a safe method of identification of the four species is examination of their salivary-gland chromosomes. Five chromosome strands are present in the salivary-gland nuclei of each of the four species. Four of these strands have disk patterns sufficiently similar in all species so that they can easily be recognized and homologized. The fifth strand, which corresponds to the third genetic linkage group (the third chromosome), is rather similar in *D. paulistorum* and *D. equinoxialis*, but quite differently built in *D. willistoni* and *D. tropicalis*. Examination of the third chromosome is therefore sufficient for identification of the species, except that *D. paulistorum* and *D. equinoxialis* have to be distinguished by less striking differences in other chromosomes.

A detailed comparison by Burla of the external morphological traits of the four species, and a comparison of the genitalia made by Malogolowkin, disclosed several small differences which, after some practice, suffice to distinguish the species. These distinguishing traits are subject to some geographic variation within species, however, which somewhat complicates the situation. Thus, whereas *D. willistoni* from southern Brazil always differs from *D. tropicalis* in the position of the anterior scutellar bristles, *D. willistoni* from equatorial Brazil shows a variation that makes this trait no longer reliable.

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DIVISION OF HISTORICAL RESEARCH

Cambridge, Massachusetts

A. V. KIDDER, *Chairman*

In archaeology it is always difficult, often impossible, to adhere to a prearranged schedule of field work. The archaeologist never knows what lies underground: its quantity, the state of its preservation, or the often entirely unexpected leads and problems it may open up. Also, he must be prepared temporarily to abandon any given undertaking because of some reported discovery which, for one reason or another, must at once be exploited. This is particularly true of work in the Maya area, in which so little actual excavation has been done that one can seldom predict what or how much or how little one is going to find; there is so great an amount of unexplored country that at any time may come word of a ruin of such obvious importance that it must immediately be given at least preliminary investigation.

The finding of the unique wall paintings at Bonampak, described in the last two Year Book reports, was a case in point. Another was the discovery, in 1948, of the extraordinarily rich tomb of the Miraflores phase at Kaminaljuyu, in the outskirts of Guatemala City. The clearing of this tomb not only took the time of two staff members for many weeks and further required many months for the study of the specimens recovered, but also proved that native Middle American culture had reached so high a state of both technological and social advancement at what had formerly been believed to be a still formative period that future investigation of the origin of Middle American civilization will have to be rather radically reoriented.

The Division's troubles at Kaminaljuyu did not end with 1948. The upper benches of the tomb, which lay several meters down

from the top of a 20-m. mound, could not be entirely excavated during that year without burrowing too deeply for safety into a tremendous overburden of hard-packed earth. So, with labor kindly supplied by the Government of Guatemala, the off season was employed in cutting it away, with the result that a second tomb, set somewhat higher, came to light. The extremely difficult task of its excavation and the recovery of its many mortuary offerings was carried out by Mr. Shook.

To Mr. Shook also belongs the credit for identification of a hitherto unrecognized stage of culture older than Miraflores but younger than one we have called Las Charcas. The original find, a burial accompanied by much pottery, was made in the side of a road-cut west of Guatemala City in the Department of Sacatepequez; this name has been assigned to the phase. Subsequently, excavation for the storage tank of a gasoline station near Chimaltenango yielded a further large Sacatepequez collection.

Study of the enormous amount of Miraflores material from Kaminaljuyu, of the Sacatepequez specimens, and of a rich new Las Charcas find has shown that these three phases were sequent stages in the (we believe very long) development of an important pre-Classic highland culture that culminated in Miraflores. The forerunners of that culture, even in Las Charcas times far from primitive, are still unknown, and we cannot as yet explain the apparently abrupt and certainly very great change marked by the opening of the Classic Esperanza phase at some time during the early centuries of the Christian Era.

Establishment of the Las Charcas-

Sacatepequez-Miraflores sequence contributes significantly to knowledge of Guatemala highland prehistory. From the broader view of the history of art and technology, its potential value is great, for it provides a large and fully documented body of data to supplement our scanty knowledge concerning such aspects of cultural growth as developments in the techniques of pottery making and the life histories of decorative styles. Much of our theorizing on these matters has been highly speculative, because based on series of specimens whose relative ages are uncertain. The only weakness of the present sequence—and it is of course a very serious one—is due to our ignorance of the amount of time that elapsed between earliest Las Charcas and latest Miraflores. For all we now know, it may have been two hundred or a thousand years. But there is hope that further perfection of methods for employment of radioactive elements for determination of the age of archaeological specimens may eventually permit reasonably accurate dating.

A second unplanned investigation was made necessary by road work at Asuncion Mita in eastern Guatemala, where in the elimination of a curve some large mounds were being cut down. In one of these, previous digging by pot hunters had exposed an earlier structure containing vaulted chambers. Mr. Strömsvik accordingly went to Asuncion Mita in April to make record of such parts of the building as had been exposed. Both architecture and pottery seem to indicate connections with Copan during the so-called Acropolis Period. During his visit, Mr. Strömsvik took opportunity to reconnoiter the region, mapping and collecting potsherds from a number of other sites.

The final season of Mr. A. L. Smith's survey of the Guatemala highlands was devoted to the Departments of Quiche,

Alta Verapaz, and Chimaltenango. Mr. Smith revisited Nebaj, Quiche, where he made remarkable finds in 1946 and 1947. This year a tomb, located in 1947, was excavated. Among the mortuary offerings of pottery and jade was a vessel, apparently a trade piece from Alta Verapaz, which is believed to date from the early years of the Late Classic Period. If this is confirmed, it will show that part at least of what we have considered the Early Classic Period of Nebaj was contemporaneous with the beginning of the Late Classic of Peten; in other words, that we must recognize a certain amount of cultural lag in the highlands.

After a survey of the San Andres Sajcabaja region of Quiche, where a number of large sites were mapped, Mr. A. L. Smith, accompanied by Mr. R. E. Smith and Dr. Stephen Borhegyi, proceeded to Alta Verapaz. Sites in the neighborhood of Coban and in the upper and middle drainage of the Rio Polochic were examined. Some of these contain remarkably fine construction in which very large and accurately cut stone slabs were used. Potsherds were scarce, but those that were recovered and certain vessels from a tomb make it evident that the ruins in question date from the Late Classic Period.

Finally, A. L. Smith visited the ruins of Mixco Viejo in the drainage of the Rio Grande. From this extensive site, known to have been occupied at the time of the Spanish conquest, he recovered a large collection of potsherds illustrating the hitherto little-known wares of the sixteenth century.

Mr. E. M. Shook, as already stated, excavated a second rich tomb in the great Miraflores phase mound at Kaminaljuyu. The specimens from the tomb, hundreds of thousands of potsherds from the fill of the mound, more thousands from various other mounds at Kaminaljuyu that are

being cut down for brickmaking, and still others from road operations to the west, are being classified and studied by Mr. Shook and the Chairman.

The most important field operation of the period under review was the Campeche expedition of Dr. George W. Brainerd and Mr. Karl Ruppert. Past work of the Division had developed a sound framework of knowledge relative to much of the southern area of the Maya and to northern Yucatan. There existed, however, an intervening area that was but sketchily known and little understood, our lack of knowledge being particularly acute in respect to ceramics. Although this little-known area stretches across the peninsula from coast to coast, it seemed of particular importance to gain knowledge of the so-called Rio Bec and Chenes areas of eastern Campeche. By making a survey of the pottery of these areas it was hoped that relationships might be established with the Peten region to the south and Yucatan to the north, and that the cultural development of Yucatan might thus be anchored more firmly to the relatively well dated cultures of the south. Such linking up of southern and northern areas seemed of particular importance before embarking upon any new operations in Yucatan.

By arrangement with the University of California at Los Angeles and the Southwest Museum, Dr. Brainerd obtained leave from those institutions for a period of six months to carry on this work for the Division. He was assisted by Mr. Ruppert. During the winter and spring they conducted excavations at the Chenes sites of Santa Rosa Xtampak and Dzibilnocac, and at a number of Rio Bec locations centering about the site of Xpuhil. At the time of writing this report we record that the materials collected are being analyzed; the study has progressed far enough, however, to indicate that the Chenes-Rio Bec archi-

tectural styles and the associated pottery are in part contemporaneous with the Puuc remains in Yucatan and with the Late Classic (Tepecu) in the Peten. The Peten association should provide approximate dating, in terms of the Maya calendar, of Chenes-Rio Bec and Puuc remains, a dating that has at times been hotly debated. There is every reason to hope that the work of Brainerd and Ruppert has made an important advance toward solving the relative chronology of the northern, intermediate, and southern areas, and that the work also will throw light on cultural influences between areas.

Laboratory and desk work again occupied a large proportion of the efforts of the staff. Miss Shepard has continued her work in ceramic technology. A special project dealing with pottery of the southwestern United States and designed to acquaint archaeologists more generally with the applications and significance of ceramic technological data is nearing completion. Miss Shepard has also given time to the preparation of a ceramic handbook for the use of archaeologists. Miss Proskouriakoff has brought to completion her initial studies of Maya sculpture. It is anticipated that this work will go to press by the end of this year. During the period under review Mr. Thompson completed and submitted the manuscript of the introductory volume of his studies of Maya hieroglyphic writing. This volume is now in press. Similarly completed and in press is Mr. A. L. Smith's work on the excavations at Uaxactun. Prior to entering the field with Dr. Brainerd, Mr. Ruppert continued his study, preparation, and arrangement of unpublished materials dealing with earlier activities of the Institution at Chichen Itza. Dr. Morris made further progress toward the publication of his researches in Southwestern archaeology. Although by

far the greater portion of his efforts was devoted to administrative duties, Dr. Pollock gave some time to his study of Yucatan architecture.

Dr. Norman A. McQuown, by arrangement with the Department of Anthropology of the University of Chicago, again gave part of his time to the Institution for researches in Maya linguistics. Dr. McQuown spent five months in Guatemala, working mainly on the Mam language, but giving some attention to other highland Maya languages, to Xinca, and to arranging for collaboration with a number of individuals in the field. Dr. McQuown's field trip marks the end of active participation by the Institution in the field of Maya linguistics. It is hoped, however, that the work will continue under the auspices of the Department of Anthropology of the University of Chicago.

Mr. Roys spent two months in Yucatan in continuance of his studies of native Maya literature and the history of the Maya area. As in the past, he devoted much of his time to field research bearing upon the political geography of the region at the time of the Spanish conquest. He also gave special attention to the search for conquest-period sites that might merit particular attention under the Division's proposed program of operations in Yucatan.

Most of the above-noted activities have been devoted to winding up the over-all study of the Maya and to clearing the deck for intensive research on the archaeology and history of northern Yucatan. In focusing its attention on this field, the Division is returning to the area in which, over forty years ago, opened the long and fruitful career of Sylvanus Griswold Morley as a Mayanist.

With Morley's death on September 2, 1948, the Maya, ancient and modern, lost

their most tireless and effective advocate. His whole adult life was dedicated to the furtherance of Maya research. That he was able to accomplish so much was due to a unique combination of scholarly ability, skill as a promoter, unbounded energy, and limitless persistence. His firsthand contributions as explorer, recorder of texts, and student of the hieroglyphs were outstanding. His driving enthusiasm resulted in the entrance of Carnegie Institution into the Maya field. He lost no opportunity to induce agencies to co-operate or to undertake independent investigations. He was thus largely responsible for the fact that so many persons have been able to devote themselves to Maya studies.

Morley early realized that in the last analysis any branch of research is made possible only by popular understanding of its aims and appreciation of its value. He was therefore tireless in publicizing the Maya by lectures and writings. With the same end in view, and also to preserve for the future the finest examples of Maya architecture and sculpture, he inaugurated at Chichen Itza and continued at Quirigua and Copan the custom of stabilizing and repairing excavated buildings and re-erecting fallen monuments. This has greatly helped to stimulate interest in their antiquities on the part of the governments of the countries in which these ruins are situated, and has led to the preservation of much that might otherwise have been lost.

Morley's scientific, practical, and promotional accomplishments were many. But, in the long run, undoubtedly the greatest was his success in inculcating confidence in the good faith of American scientific agencies and in bringing about the close and cordial relations, both personal and intellectual, that now exist between those scholars of the United States

and of Latin America whose common interest is in the prehistoric past of the New World.

Shortly after the close of the period under review, Dr. George Sarton will retire from the staff of the Division. His retirement will terminate an association of thirty-one years. Dr. Sarton's unceasing labors in the history of science have resulted in transforming a previously unorganized and largely unrecognized field of study into a recognized discipline. Though his retirement will mark the end of the Institution's activities in the history of science, his efforts have assured a continuing interest, both in this country and abroad, in this field of learning.

On June 11, 1949, the Chairman received the honorary degree of Doctor of Science from the University of Michigan.

GUATEMALA HIGHLANDS

EDWIN M. SHOOK

The cutting away of Structure E-III-3, Kaminaljuyu, to obtain material for bricks continued throughout the past year. The great mound, as previously reported (Year Book No. 47, pp. 215-217), is the largest individual structure of some two hundred which make up the ruins on the southwest edge of Guatemala City. The salvaging of the invaluable archaeological material and data from the excavations was possible through the co-operation of Sr. Moises de Leon, superintendent of the government brick factory. He not only placed several laborers under our supervision, but permitted his workmen to be shifted here and there on the mound to facilitate the recording of the exposed remains.

Information was gathered on the architectural development of Structure E-III-3 from a small semicircular adobe unit about 2 m. high (no. 1) through six successive major additions. The final stage (no. 7)

was a massive, flat-topped, rectangular pyramid over 20 m. in height and measuring 70 by 90 m. at the base. Ceramic material obtained from the fill of each unit indicated that the long sequence of architectural activities took place during the Early and Middle Miraflores phases of the Pre-Classic Period. The lavishly stocked Tomb 1, reported in Year Book No. 47, had been cut through the top of Structure 5. A similarly constructed and equipped tomb, no. 2, was found during the past field season. It had been dug through the top of Structure 6, the next pyramid, which completely encased Structure 5 and Tomb 1.

Tomb 2 occupied a position just west of and higher than Tomb 1, its east wall actually penetrating the upper west bench of the older tomb. Although less carefully constructed and less richly furnished, Tomb 2 provided more information because it had not been disturbed by the brick-factory workmen as had Tomb 1. Prior to the roving of the tomb with timbers, the principal individual, a mature adult, had been laid horizontally, head to the south, on a low wooden table or platform resting on the tomb floor. The body was completely painted red and probably dressed or wrapped. Two children, about eight years of age, had been sacrificed and placed in an extended position on the tomb floor just west of the principal body. Another skeleton, that of a young adult, lay extended, face downward, on one of the east benches above the roof of the tomb. Over one hundred pottery vessels, some containing ash and charcoal, had been placed on the surrounding benches after the timber roof was laid.

In contrast with Tomb 1, only a few pottery vessels were found on the tomb floor. Here, however, were most of the nonpottery objects: mica sheets, sting-ray

tails, fossil fish teeth, stuccoed containers (possibly gourds), quartz crystals, water-worn stone pebbles, basalt implements, bone spatulas and ornaments, mosaic mirrors of pyrite and of crystalline hematite, obsidian pellets and flake-blades, tubular jade beads, mosaic sets, and a mask or headdress heavily incrustated with jade elements. The last was found face down off the southeast corner of the wood platform that had supported the principal body. The decay of the platform, or a fragment of falling roof timber, may have rolled the object to the tomb floor. The backing of wood and leather, we believe, was still firm when this occurred, and the heavy jade elements remained in position until falling material settled around and covered the whole. This earth fortunately maintained the original form of the object fairly well after the backing rotted, and the recording and removal of the jade elements more or less in their original positions were possible. The headdress or mask has been reconstructed by the artists of the Archaeological Museum of Guatemala.

After Tomb 2 was roofed, additional offerings were placed on the benches and the large space was filled with earth from the roof level to the floor of Structure 6. An adobe floor then covered the entire tomb area, permitting the use of the pyramid top again. At the same time, we think, the last great increment to E-III-3 was started. Prior to the completion of Structure 7, which added some 4 m. to the total height of the mound, Tomb 2 was re-entered and partially rifled. The looters disturbed only the principal skeleton, from the pelvic region to the head; we found none of those bones in place. We did find scattered human bones and teeth in earth mixed with red paint, well above the tomb floor, apparently from the main skeleton and cast aside by the looters. The jade ear ornaments, necklace, and pendants

which normally would adorn a person of such obviously high rank were entirely missing. The jade-incrusted headdress and beads lay off to the sides of the wood platform and were overlooked by the looters, perhaps because they were covered by debris.

The evidence strongly suggests that only one generation (twenty-five years or less) elapsed between tombs. The occupant of Tomb 2 may have been the immediate successor of the individual buried in Tomb 1. Some striking changes had taken place in Kaminaljuyu in those few years. A higher percentage of Usulután ware vessels was found in Tomb 2, many of them similar in shape to fine, incised red ware bowls, with everted rims and three sharply pointed nubbins feet. The latter vessels, although among the most common in Tomb 2, did not occur in Tomb 1. They apparently developed during the interim for specialized ceremonial uses, and often are found containing ashes and charcoal. As a result of the burning, the bowls' interiors frequently are blackened. Tomb 2 contained no "mud" pots or frog effigy vessels of fine red ware, as did Tomb 1, no stone vessels, mortars, or "mushroom" stones. The less care shown in the construction of Tomb 2, the fewer offerings, and the evidence of looting may indicate that the principal individual buried there had not been so successful a ruler or priest as his predecessor, or that economic conditions at the time of his death were more severe than at the beginning of his rule.

Structure E-III-3 is only one of a number of ancient structures being dismantled in Kaminaljuyu. Periodic visits to the various excavations helped to gather much information that otherwise would have been lost. Fortunately, one of the principal mound groups has been set aside through the civic interest of the owner,

Sr. Arturo Samayoa, to be preserved as a national monument. The National Institute of Anthropology and History has appointed a caretaker, whom we have trained, to maintain the monument and to collect archaeological material as it is excavated elsewhere in Kaminaljuyu.

Modern road construction and trenching for pipe lines led to more discoveries in the past year that amplified knowledge of the oldest known ceramic phase in the Guatemala highlands, the Las Charcas, and of the subsequent Sacatepequez phase. Both of these predate the long Miraflores phase. An ancient pit, containing a rich deposit of apparently pure Las Charcas material, was found in Colonia Progreso, southeast of Mound B, Kaminaljuyu. The material, sealed by a heavy layer of obsidian flakes, included a wide range of ceramic types illustrating many specialized features. Among the latter were spouted and shoe-shaped vessels, effigy monkey heads broken from vessel walls, small solid crudely hand-modeled monkey figurines, two cylindrical and two stemmed flat seals or stamps. Also found were many burned adobe fragments bearing impressions of leaves, corncobs, and other vegetable objects, carbonized seeds of several fruits, and ashy remains of woven fibrous material. The Colonia Progreso find represents the first large lot of Las Charcas material recovered by a controlled excavation.

Further search along the newly constructed Roosevelt Highway west of Guatemala (see Year Book No. 47) disclosed more deposits of the Sacatepequez phase, usually in deep rectangular or circular bottle-shaped pits. The pits occur sporadically along the road from San Bartolome Milpas Altas to Chimaltenango. Archaeological sites with mounds were located in the vicinity of the pits, but direct associations were difficult to ascertain, because the surface material collected from

these sites shows that occupancy continued into later periods. The ruins, in order along the highway, are Xaraxong, Chacaya, Santa Maria Cauque, Manzanales, Los Pinos, San Roberto, Rio Sumpango, Tejar, Tejarcito, Santa Fe, El Rancho, and Santa Sofia. The last six sites are in the Chimaltenango Valley; the others, in the Rio Sacatepequez Valley.

Advantage was taken of an opportunity offered by Mr. Hugh Craggs, of Guatemala City, to accompany him on an automobile trip through southeast Guatemala, Salvador, and Honduras. A brief reconnaissance was made of eastern Salvador, the coastal plain of Honduras north of the Gulf of Fonseca, and the highland valleys of Zamorano, Tegucigalpa, and Comayagua. The archaeological museums of Comayagua and Tegucigalpa and the ruins of Tenampua and other sites were visited.

Firsthand observation of the topography and climatic conditions of eastern Salvador and of southern and central Honduras directs attention to the importance of the natural intercoastal corridor running from the Pacific coast via the Rio Goascoran Valley to the upper Comayagua, thence to the Ulua Valley and north coast of Honduras. Through this natural funnel must have flowed not only aboriginal commerce, but forces affecting the cultural development of much of southern Mesoamerica. Eastern Salvador and the upper Comayagua Valley have a concentration of ancient remains showing occupancy over the known range of pre-Columbian history. It is most desirable that a study be made of the Rio Goascoran drainage from the Pacific lowlands to the upper Comayagua Valley.

Shook also visited the archaeological zone of Chalchuapa, where the Salvador Government for several years has carried on intensive excavation and repair of the

principal structures, under the able direction of Mr. Stanley H. Boggs.

In southeast Guatemala a record was made of the small, hitherto unreported site of San Juan Las Minas, 1 km. west of Asuncion Mita. The extensive, well known ruins of Asuncion Mita, south of the modern town, have been noted for their excellent state of preservation, the quality of the thin-slab masonry, and the corbeled arch used by the builders to roof their structures. This is the most southern site on record where the Maya-type vault was utilized. Despite the importance of these ancient buildings, they were being destroyed to obtain stone for road construction. Shook submitted a report to the Institute of Anthropology and History which curtailed the quarrying of the site except for the main structure, already beyond saving. Strömsvik later visited Asuncion Mita and obtained as full a record as possible of what remained (see p. 231).

In 1945 the Guatemala Government began an agricultural colonization project in the southeastern corner of the Department of Peten. Poptun, a small village near the headwaters of the Rio Machaquila, was selected for the permanent site of the colony and renamed Poptun. The operation entailed intensive land clearing for agricultural experimentation, surveys, building of the physical plant, and opening of a highway to Cardenas on the Rio Sarstoon. The road, to be completed in 1949, is being constructed from Poptun south through San Luis and north from Cardenas. Since 1945, reports have been received repeatedly from individuals and through the local press of archaeological discoveries made in Poptun, Cardenas, and along the highway. This past year the governor of the colony, Col. Ernesto Alvarez, invited the Institute of Anthropology and History and Carnegie Institution

to visit Poptun and report on the finds. Lic. Adolfo Molina, then Director of the Institute, R. E. Smith, and E. M. Shook went to Poptun in November and spent four days recording the cultural material, and mapping and photographing the archaeological sites.

Five ancient sites—Los Cimientos, Hortaliza, Sabana, Poptun, and Petensuc—were studied briefly during the visit. They lie roughly in an east-west line, north of the modern settlement, between the drainage of the San Pedro and Machaquila Rivers. The remains of Poptun are the best preserved architecturally. They undoubtedly represent what was the region's civic and religious center. There are three known groups, South, Central, and North, connected by a broad artificial causeway with a low masonry parapet on each side.

The North Group consists of five rectangular platforms of fairly well cut stone masonry on top of a leveled and terraced limestone hill. The southern base of the hill also was terraced, but no masonry stairway connected the lower with the upper terraces. Apparently a pathway zigzagged up the steep hillside to the structures on top. The causeway from the South and Central Groups joined the great basal terrace of the North Group. Here a single plain stela of limestone was erected.

No evidence was found in Poptun or in the small outlying sites that the Maya here used the typical vault or even masonry buildings. All the masonry noted in the area was for substructures, terraces, and low walls bordering courts, terraces, and causeways. The substructures were low rectangular platforms to support houses and temples constructed of perishable materials.

Poptun evidently was never a major center. It may have served the civic and religious needs of a comparatively small

population scattered widely throughout the area. Although there is evidence from the cultural material of occupation from Pre-Classic (Chicanel) to Late Post-Classic time, the period of greatest activity was during the Late Classic (Tepeu).

Engineers of several American oil companies have for the past two years been making an intensive topographical survey of the Department of Peten. They have discovered many hitherto unreported archaeological sites and caves containing ancient cultural material, and deposited their data, maps, and specimens with the Division. Dr. Barnum Brown, of the Sohio Oil Company, made important discoveries along the Rio de la Pasion from the junction of the Santa Amelia to the confluence of the Rio Salinas or Chixoy. He recovered quantities of petrified bones of Upper Pleistocene fauna on bars and barrier reefs along the Pasion. They had been washed out from deposits somewhere on an eastern tributary of the stream, possibly the Rio Santa Amelia. One bone fragment, as yet unidentified but thought to be that of a sloth, has three sharp V-shaped cuts on the unbroken external surface. These cuts, according to Dr. Brown, were made in living tissue. If the cuts were made by man, as Dr. Brown thinks, this is the first evidence found in Guatemala of man associated with ne extinct fauna.

Dr. Brown also discovered an artificially built island in the Rio de la Pasion, above the ruins of Seibal, and a previously unreported sculptured stela at the latter site. He collected large samples of pottery from various points along the river, including Seibal and Altar de Sacrificios. The ceramic material shows a range of occupancy in southern Peten from the Chicanel phase of the Pre-Classic through the Early and Late Classic periods.

Two efforts were made during the spring

of 1949 to locate the conquest town of Nito, an important commercial center of the Indians. The town was conquered by Gil Gonzalez in 1524 and renamed San Gil de Buena Vista. Apparently the site proved unsuitable to the Spaniards and they soon abandoned it for a new location on the Rio Dulce near the sea. The Spanish name, often reduced to San Gil, as well as the Indian name Nito, continued to be applied synonymously to the new town site where, in April or May 1525, Cortes arrived after his extraordinary march overland from Mexico to Honduras. Cortes found his countrymen starving at San Gil and shortly after his arrival he moved them to Honduras. Since the abandonment in 1525, both sites, San Gil near the sea and Nito the original Indian trading town, have been unoccupied and their exact locations lost. It is of historical significance to place these sites and especially to obtain from Nito data on cultural material anchored firmly in Christian chronology.

A launch and other facilities were generously provided by the United Fruit Company through the courtesy of Mr. William Taillon and Mr. Edward Farnsworth. The latter accompanied Shook on the second expedition. Two areas were intensively investigated. The first was the south side of the Golfete, the body of water connecting Lake Izabal with the Rio Dulce, which existing information suggested as the most likely area in which to find Nito. Several days were spent along this shore, penetrating the dense tropical jungle wherever possible and pushing a dugout canoe up the tributary streams. Finally an elderly native of unusual intelligence was encountered. He knew the area well, including a navigable stream, an abandoned property, and a site with mounds, all still known as San Gil. He had discovered and removed a frag-

mentary bronze bell from the site about eighteen years ago. The bell was later seen and recorded by Shook, and efforts were made to have it sent to the Guatemala Museum.

We followed the Rio San Gil upstream for approximately 3 km. from the Golfete. Only the first kilometer was navigable in a dugout canoe, the next 2 km. having been blocked by fallen trees and by sand bars, but the entire distance would be navigable by canoe if the stream channel were cleared. At the 3-km. point two shallow, swift-running branches join to form the Rio San Gil. Here the land is level, fertile, and at present heavily overgrown with dense tropical rain forest. This latter condition so obscured the area that, though we searched over a wide zone, we were unable to locate the mounds where the bell had been found. The general locality, Shook nevertheless believes, must have been the site of Nito. Strong evidence for it is the survival of the name San Gil for the place, the river, and a high mountain rising immediately behind, as well as availability of a fine water supply and access by canoe to the Golfete.

The second area investigated extends about 4 km. along the south bank of the Rio Dulce, from its mouth opposite Livingstone to the foot of the mountain range paralleling the coast. Here undoubtedly was the later settlement of San Gil de Buena Vista, where Cortes found the Spaniards. Most of the 4 km. may be eliminated as unfit for settlement because of swamps and lack of fresh water. Two places were found to offer adequate facilities to sustain a small colony. One, on elevated and well drained ground 2 km. southwest and upstream from Livingstone, still is known as Buena Vista. 'An excellent spring of fresh water issues from the base of the hills only about 50 m. back from the Rio Dulce. No ruins were visible,

but reports from the local people tell of ancient artifacts being found when the land is cleared for corn planting. The other possible location is on a high bluff at the outlet of the Rio Dulce, known today as Herreria Point. A fresh water supply from two small streams is available and there is a certain amount of cultivable land. A small preconquest Indian site (Herreria) was found overlooking the Caribbean Sea 500 m. south of the Rio Dulce. Broken china, crockery, and glass bottles gave evidence of occupation during Spanish colonial and modern times, but nothing definitely assignable to the early colonial period was found.

While awaiting transportation in Puerto Barrios, Shook mapped and recorded a previously unreported site called San Manuel. The ruins are situated on the south bank of Rio Cacao and are cut by the auto road to Santo Tomas. The principal structures are so grouped around a plaza as to form an oval, in contrast with the normal rectangular arrangement. Some forty or more mounds, the majority low house platforms, compose the site. All are substructures built of earth. The largest structure, about 5 m. in height, has its surface partially faced with water-rounded boulders. No ball court, stone sculpture, or surface pottery was found to suggest the occupation period of the site.

GUATEMALA HIGHLANDS

A. L. SMITH

The 1948-1949 field season was the final of four seasons devoted to archaeological reconnaissance in the Guatemala highlands. As in previous years, the main purpose of the expeditions was to obtain as much information as possible in a minimum period of time and with little excavation. In most cases sites were roughly mapped, detailed measurements were taken

of individual buildings, a photographic record was made, and pottery was collected. In some instances perspective sketches were made of whole sites or of individual groups. The season included expeditions to sites in five areas: Sacapulas, Nebaj, San Andres Sajcabaja, all in the Department of Quiche; various sites in the Department of Alta Verapaz; Mixco Viejo in the Department of Chimaltenango.

Mr. A. L. Smith, assisted by Sr. Gustavo Espinoza, began the season at Sacapulas and visited three sites: Chutixtiox, Xolpacol, and Chuchun. At Chutixtiox, a late hilltop site, a tomb was found associated with an early structure. Unfortunately it had been robbed in ancient times, but the excavation yielded a few objects from the tomb and from the entrance.

Xolpacol, also a late hilltop site, proved, although small, to be extremely interesting. Among its ten structures were a well preserved late-type ball court, a small round platform supporting a round superstructure with four doorways, and a low platform upon which rested twin temple mounds. The main temple mound stood in the center of a small plaza. It had been dug into and a tomb exposed (see Year Book No. 46, 1946-1947, p. 185). A very good sample of pottery was recovered from the surrounding fields and down the steep slopes which had been used as refuse dumps.

Chuchun is a small valley site. Of the eight structures noted, the most important were an open-end ball court and two fairly large temple mounds. A small surface collection of pottery was recovered.

Leaving the Sacapulas area, Smith, accompanied by Sr. Cesar Tejeda, assistant archaeologist, and by Mrs. Smith, moved to Nebaj. For the remainder of the field season Mrs. Smith took charge of the food and the gathering of surface pottery collec-

tions. While in the Nebaj area time was found to visit Finca San Francisco, belonging to the Brol family; from here the ruins of Chipal were visited.

The major effort at Nebaj was the further investigation of the large mound excavated during an earlier field season (Year Book No. 46, pp. 185, 186). A tomb was found that proved to be of the same ceramic period as the earliest tomb previously discovered, late Early Classic or early Late Classic. The grave was relatively rich in furniture, and additional material was found in the dirt that had caved in from the sides of our original excavation. Before leaving the site, we completely filled the hole.

Two small groups of mounds just north of the main ruins of Nebaj were mapped. Both groups have open-end ball courts leading into small plazas with an altar mound in the center, the ball court being the principal structure in each group.

The site of Chipal, which is of the Huil type, namely, open end ball court and adjoining plaza with an altar in the center of the latter, is in a very poor state of preservation. The ruins are used as a corral, and stones from the structures have been removed to build walls. No map of the ruins was made, as Burkitt had published one. No pottery was found at the site.

From the Nebaj area the expedition moved to San Andres Sajcabaja. This area had previously been reconnoitered from the air (Year Book No. 46, p. 187). Eleven sites were visited: La Lagunita, Xepom, Xolja Alto, Xolja Bajo, Pantzac, Patzac, Llano Grande, Los Cimientos, La Iglesia, Chuscup, and Xabaj. These were located on a tracing of a map of the municipality.

La Lagunita, a large site, consists of two groups separated by a deep ravine. Group A has fourteen structures, an enclosed court, and several plazas. In the

main plaza is a plain stela, beneath which someone had dug. Six of the mounds are large, but no traces of superstructures were found. Group B, with thirteen structures, has two possible ball courts, one with open ends, the other closed but with no apparent end zones. The rest of the structures are platforms surrounding courts or small plazas. Both groups are surrounded by deep ravines and lend themselves to defense. Pottery from the site seems to place it in the Late Classic Period.

Xepom, Xolja Alto, and Xolja Bajo are small sites. Xepom and Xolja Alto are on the tops of hills overlooking the Rio Agua Caliente; Xolja Bajo is in the river valley. Very few architectural details of interest were found and only a small amount of pottery was collected. From the sherds recovered, Xolja Alto and Xolja Bajo appear to have been occupied in Late Classic times.

The largest site visited in this area was Pantzac. The ruins are not unknown, having been mapped by Sapper and briefly described by Maudslay. Sapper's map is extremely accurate and needs few changes. There are thirty-eight mounds still in existence, but Sapper shows others which have been razed; many of the architectural details that he indicates have long since disappeared. The masonry is of well cut and faced blocks which the inhabitants now living in the ruins use to build their houses and fences. The site divides itself into about five groups containing temple mounds and long structures surrounding plazas and courts, altar mounds, platforms, and a sunken court. There are two ball courts, one with open end zones and an adjoining plaza not unlike the Huil type, another with end zones probably closed with low walls. Pottery, found in quantities in the surrounding fields, places the occupation of the site in plumbate times. Although probably not built as a defense

site, Pantzac lies on a plain surrounded by deep ravines which would afford easy defense.

Patzac, like Pantzac, is surrounded by deep ravines. It is a large site having thirty-four structures. These are mostly in the two main groups, the rest being in scattered groups of two and three mounds. Each of the main groups has a ball court with closed end zones. Other structures take the form of temple pyramids, platforms, and altars. Several of the structures support low walls of superstructures. The pottery collected shows that this site was occupied at the time of the conquest.

Llano Grande lies in a plain, and the site definitely was not built with any idea of defense. The ruins consist of a large rectangular platform, reached by a stairway on its south side, and supporting four mounds and a sunken court. The last, which is at the west end of the platform, is probably a ball court. To judge by the pottery recovered, the site was probably occupied during the Late Classic Period.

The best-fortified site visited in the area was Los Cimientos, completely surrounded by steep ravines, the only entrance being over a causeway. Nine structures at the highest point comprise the ceremonial center. Eight of these follow the edges of terraces and form the sides of a small plaza; the ninth structure, a temple mound, is in the plaza. Two of the nine structures are temple mounds, seven are low platforms, most showing signs that they once supported superstructures. The main feature at the site is the terracing on its east, south, and west sides. The terrace walls are built against natural levels running in all directions and varying in height. Reaching to the side of the ravine, the terraces are quite extensive and may once have been used as sites for houses of perishable material. Surface pottery is

scarce, but a small collection places Los Cimientos in the conquest period.

La Iglesia, the main structure of which has been turned into a crude modern church, has two groups. Group A lies on a large oval hill which rises about 50 m. above the surrounding plain. It consists of a rectangular court surrounded by a low wall with an entrance in the south side. All but one of four platforms in the court carried stone superstructures. The superstructure of the largest was of great interest, as the walls stood to considerable height in some places, and the method of construction could be examined in detail. A good sample of pottery of the plumbate period was obtained from this group. Group B is on the level of the plain. It is made up of a plaza with a large rectangular platform on each of three sides. No masonry was showing, and there was no evidence of superstructures.

Chuscap was visited because of a reported subterranean passage that had never been explored. It turned out to be a bottle-shaped hole in the center of a small field on a hill near the Rio Agua Caliente. In shape it resembles a *chultun*, having a narrow neck for an entrance, with stones around the top, which was covered with a stone lid. Nothing was found in it and its purpose could not be determined. No structures of any kind were found in the vicinity.

The last site visited in the San Andres Sajcabaja area was Xabaj. It is a small group of three platforms strung out along the top of a hill high above the plain. The platforms, which are almost square, still support the remains of superstructures. Two of the structures had each a small modern shrine on top, and the third had six. Several of the shrines contained small carved monuments. No pottery was recovered. According to the local inhabi-

tants, Xabaj is an important place of worship today.

The fourth expedition was to Alta Verapaz, the personnel being Mr. and Mrs. Smith, Mr. R. E. Smith, and Dr. Stephen Borhegyi. Ceramic studies were in the charge of R. E. Smith and are reported by him below. Perspective sketches of ruins were made by Borhegyi. The following sites were visited: Esperancita, Tampoma, Omaxa, Canchunac, Las Tinajas, Pueblo Viejo, Seacal, Chijolom, Chichen, Santa Elena, Chicuxab, Valparaíso, and Chin-chilla.

The expedition's first base was Finca Mocca, belonging to Mrs. Robert Hempstead. The finca lies northwest of La Tinta, a village on the Rio Polochic. The first ruin visited was Esperancita, a small site consisting of eight mounds and several terraces on top of a sloping ridge. The ridge rises in natural terraces, the upper three having been artificially leveled and faced with rough stone slabs. Large stairways lead from one terrace to another. The lower terrace supports the main group. Here six long low platforms surround a small plaza with a rectangular platform in the center. The second terrace supports a long low platform. There were no structures in the third. The platforms are not oriented to one another, as they follow the contour of the ridge. A sketch was made of this site.

Tampoma has five small groups spread out on the flat valley floor. A small river, the Tampoma, flows through the ruins to join the Polochic. The largest group has what appears to be a ball court with an adjoining plaza with long low platforms on three sides. Off to one side is a low mound with a plain stela and altar in front of it. The other groups had three or four mounds each, surrounding small plazas.

At Omaxa, close to Tampoma, are several small mounds and one large one. Un-

fortunately the site was so overgrown that no work could be done. Canchunac, west of Finca Mocca, consists of a series of terraces and one mound.

After leaving Finca Mocca the expedition moved to Finca Las Tinajas on the south side of the Rio Polochic, where two ruins, Las Tinajas and Pueblo Viejo, were visited.

The ruins of Las Tinajas, also called Tzesac and located on Sapper's map as Chacujal, are close to the Rio Tinaja, which flows into the Polochic. It is possible that this may be the Chacujal mentioned by Cortes in his fifth letter to the Emperor Charles V. It is a large site, at present badly overgrown. Twenty-six structures were found, a number of which supported the remains of stone superstructures. Two temple platforms stood in the center of a large plaza. The buildings were constructed of a hearting of clay and water-rolled stones faced with thin stone slabs laid in clay. It is worthy of note that no clay or thin stone slabs seem to occur in the vicinity of the ruins. A sketch was made of the site.

Pueblo Viejo is an extensive ruin not more than a kilometer west of the ruins of Las Tinajas. The mounds are piles of water-rolled stones with only a few instances of thin slabs around the base. It is very possible that these mounds formed a part of Las Tinajas that was never completed. No map was made of Pueblo Viejo because of its overgrown condition.

The expedition next proceeded to Finca Seamay and thence to Finca Arenal, both of which belong to Mr. George Koester, and which lie north of the Rio Polochic not far from the village of Senahu. At Arenal two sites, Seacal and Chijolom, were visited.

Seacal lies on top of a steep hill covered with outcroppings of rock of the type used in the masonry at the site. The main

feature of this small ceremonial group is a rectangular sunken court with sides of large, beautifully cut and faced stone blocks. The court is surrounded by rectangular platforms on the ground level above it. A sketch was made of the site.

Chijolom, a small group in which the ball court is the main feature, lies in the saddle between two hills. The ball court is the open-end type and has its sides built against the two hills. On one side terraces and stairways rise farther up the hill. Beyond a rectangular platform at either end of the ball court, terraces extend down into ravines. The masonry, the most beautifully cut and fitted seen in any part of Guatemala, was laid without the use of mortar. A sketch was made of the group, showing details of stonework.

After leaving Arenal the expedition moved to Coban, once more as guests of Mrs. Hempstead. Three sites were visited: Chichen, Santa Elena, and Chicuxab.

The ruins of Chichen are about 30 m. above the north side of the Rio Chichen. Almost all the seventeen structures are oriented to one another and are grouped around three plazas. There are rectangular platforms, altar platforms, a temple mound, and two open-end ball courts. The last are very similar to the ball court at Chijolom. No evidence of superstructures was found. A sketch was made showing the entire site.

Santa Elena, south of Coban, is a small valley site of four platform mounds, three of which are oriented around a small plaza. The fourth mound lies to the north of the plaza group. Chicuxab, a three-mound site, lies in a hollow in the hills. The three platforms are almost shapeless from having been plowed over.

After leaving Coban the expedition returned to Guatemala City via Salama. Between Coban and Salama two sites, Valparaiso and Chinchilla, were examined.

Valparaiso, a small site lying north of the Rio Coban, had been visited by Shook and Smith some years ago, when a collection of surface pottery was made and the site was roughly mapped. We now attempted to obtain more pottery, but the owner was away and the resident Indian family would not permit any work.

The two groups which make up the ruins of Chinchilla are on the slopes of two adjacent hills on the north side of the Rio Frio. The site was previously seen by Dr. Kidder and at that time was in a much better state of preservation. The main group consists of five structures: four platform mounds are oriented around the four sides of a small plaza, in the center of which is a large temple platform. The other group consists of three small mounds.

The final trip of the season was by Mr. and Mrs. Smith and Borhegyi to Finca Las Pilas, belonging to Sr. Francisco Martinez del Rosal, in order to examine the ruins of Mixco Viejo, a conquest site mentioned in early accounts. The ruins have been mapped by Sapper. Mixco Viejo consists of twelve groups spread along the flat top of a ridge completely surrounded by steep ravines. It is a well fortified place which can be entered only by a steep narrow trail, easily defended. The larger groups consist of structures surrounding, in each case, a plaza, often with a temple mound or platform in the center. The structures are not oriented to one another because they follow the edges of the ravines. In many cases the upper edges of the ravines are faced with stone. On the south side there are natural terraces where the abundance of refuse indicates that this may have been an area where houses of perishable material once stood.

The sixty-eight or more structures at the site consisted of temple platforms, long platforms with three or more stairways on

one side, altar mounds, long low rectangular platforms, twin temple platforms on a single platform, and two ball courts. The last were of the conquest type with closed end zones and a stairway at the center of each end. Although many of the structures must have had superstructures, no evidence of them was found. A sketch was made of Group B, one of the largest groups, that contained the greatest variety of structures. A large surface collection of pottery was recovered, but nothing was found in the several pits that were dug in platforms. The surface pottery contains some Early Classic, a good deal of Late Classic, and an overwhelming amount of conquest period wares. No plumbate period pottery was found.

GUATEMALA HIGHLANDS

ROBERT E. SMITH

The pottery findings of the Alta Verapaz archaeological survey were quantitatively small but typologically significant. The hilltop sites, Seacal, Esperancita, Chijolom, Chinchilla, and Samac, were especially lacking in potsherds with the exception of Seacal, which contributed about a hundred. These sites, including the ball-court site of Chijolom, probably served as shrines, and therefore ceremonial pottery normally associated with tombs and caches was mostly used. In their function the Alta Verapaz hilltop sites differ markedly from those of other sections of the country, which appear to have been fortified retreats and where quantities of utilitarian as well as more elaborate pottery are found.

A tomb with skeleton, six pottery vessels, and bone ornaments was uncovered at Seacal. Two of the vessels equate with Tepeu 3 types. A cache in Mound 1 at Esperancita contained two pottery vessels suggesting a Tepeu 1, 2-Chipoc-Chama 3,

4-Alta Verapaz II horizon. In addition, some sixty sherds were recovered from three sizable trenches. None were found on the surface. At Chijolom a trench was dug across the center of the ball court and a pit was sunk into the center of the northeast platform mound, but the only place from which potsherds were recovered was a low terrace off the southwest end of the ball court, where there was a vegetable garden. Here some thirty sherds were gathered from the surface. These indicate a Tepeu 3 to Tohil, or even later, horizon. The pottery picked up from the surface of the larger group at Chinchilla included two faceted, red ware, Z-angled sherds of Miraflores-Chicanel type. The other eight fragments recovered were too small and weathered for identification. A tomb, excavated on Finca Samac many years ago, included a skeleton and five pottery vessels. One of the latter is a Tohil plumbate specimen which dates this grave as Post-Classic-Tohil phase according to Dr. Wauchope, or as Alta Verapaz III according to Dr. Butler. On top of the hill upon which the tomb was discovered we were fortunate in finding a ready-made cut, exposing a section filled with potsherds ranging from Chipoc (Tepeu 1, 2-Chama 3, 4-Alta Verapaz II) to Yaqui, the latest pre-conquest ceramic phase.

The valley sites, Las Tinajas and Tampoma in the Polochic valley, Chichen, Chicuxab, Santa Elena, and Valparaiso in the Coban area, as a rule were well supplied with potsherds. The exception was Las Tinajas, a large site where we dug a deep pit into the center of a long low platform mound and found a handful of unidentifiable sherds. Pits were dug throughout the main plaza, from which a total of one potsherd and an effigy-head foot resulted. At Tampoma two pits were dug, one into a rock-pile mound, the other under an unmarked stela. Most of the

identifiable sherds from the former belong to the Chipoc phase, as do those from the latter pit, which also contained jade (two tubular beads and three very thin flat perforated ornaments) and a pyrite mosaic mirror fragment. Most of the sherds from this site were picked up from the surface, an ancient river bed. Because of the water-worn or generally weathered condition of these fragments, much of the material is unidentifiable, but a quantity of Chipoc types were recognized. It is likely that further study will bring to light later horizons.

In the Coban area the largest site observed was Chichen. Here we dug pits into three mounds, trenched across the center of the main ball court, and collected surface pottery. Mound III contained the earliest (Chicanel) as well as the latest recognized (Tohil) pottery. Undoubtedly the site was occupied up to the conquest, and further study presumably will prove this. Chichen is a present-day pottery-manufacturing center. Chicuxab is a small site, but the surface is literally bristling with potsherds. We did no digging here, but picked up a carefully selected collection, containing largely Chipoc types besides a few Tzakol-type and Tohil pieces. Another small site, Santa Elena, close to Chicuxab, had an abundance of pottery on the surface and inside small platform mounds, two of which we trenched. The only Chicanel-type sherds were found on the surface. The mounds and surface yielded Tzakol and Chipoc types in considerable quantity and probably later types. At Valparaiso a surface gathering contained a few Tzakol and Chipoc types and an abundance of unidentified fragments which probably form part of later cultures.

From this survey we find that in the Alta Verapaz we can recognize various phases which closely parallel those suggested by Dr. Butler (*The Maya and their*

neighbors, pp. 250-267, New York, 1940). Dr. Butler's work, however, deals for the most part with the Chixoy drainage area and includes sites in the western part of the Alta Verapaz or farther west in the Department of Quiché, an area not touched in this survey. In order to keep the ceramics of the two areas separate, we are proposing new ceramic phase names for central and eastern Alta Verapaz: Chipoc (Tepeu 1, 2; Pokom; Chama 3, 4; Alta Verapaz II; Late Classic), Seacal (Tepeu 3), Samac (Tohil; Chipal 2; Alta Verapaz III; Post-Classic). The Pre-Classic and Early Classic, as well as the later phase corresponding to Yaq'ui, will be named when further knowledge as to the distribution of the wares of these periods in the Alta Verapaz is available.

HONDURAS AND GUATEMALA

GUSTAV STRÖMSVIK

During the past season no archaeological excavation took place at Copan, but an experiment in preserving archaeological sculpture should be recorded. Sculpture that has lain in the ground for some time is subject to minute plant growth, such as lichen and fungus, whose roots loosen the tiny particles of the surface of the sculpture; rain and wind continue the erosion. The sandstone at Quirigua and the tuff at Copan are particularly liable to this action. Some years ago S. G. Morley sprayed Stela K at Quirigua with a hardening agent, but the monument is again covered with lichen and fungus. Early this season Mr. R. E. Smith sent a new hardening agent to Copan for experimentation. The six lowest steps of the Hieroglyphic Stairway were carefully cleaned and dried; the viscous fluid was then applied with a brush. It will be some years before results can be seen.

Progress was made toward completing

a report on the three superimposed ball courts at Copan (see Year Book No. 36, 1936-1937, p. 138). Considerable work also was done in amplifying, checking, and correcting the specimen catalogue at the Copan Museum as a preliminary step in the preparation of a report on the cultural material in the Copan Valley.

In March, Strömsvik went to Guatemala for consultation with the Chairman of the Division. About this time, near the town of Asuncion Mita, Department of Jutiapa, several mounds of ruins were in danger of being razed by the construction of the Roosevelt Highway, whose route lay directly across the biggest and most important mound, locally called Cerro de Laja. Strömsvik consequently went there at the beginning of April to obtain all possible information before the mounds were destroyed and to co-operate with the Institute of Anthropology and History of Guatemala, which defrayed half the costs and supplied the services of Sr. Gustavo Espinoza, who assisted most ably in the excavations and explorations.

At the Cerro de Laja, which was our chief concern, a room filled with debris was completely excavated in order to examine the structural and architectural details, particularly the vaulting. This is the southernmost occurrence of the vault so far found in the Maya area. There can be no doubt, moreover, that the structure is of Mayanoid origin, for numerous fragments of Maya Polychrome and Copador pottery were found in the debris, thereby placing the remains in the Classic Period.

There undoubtedly are other rooms in this large mound, which will soon be removed completely by the highway work. At that time the details of construction should be recorded as they become apparent.

The countryside surrounding Asuncion Mita was given a hasty reconnaissance;

Brunton compass survey maps were made of four main ruins and some minor ones. The main groups were designated A, B, C, and D (Cerro de Laja is Mound 1 in Group A). In Group A lies the best-preserved ball court, from which were removed two parrot-head sculptures now to be seen in the entranceway of a house in town. These heads, like those at Copan, were cut to stand vertically in the benches. Another less well preserved ball court is located in Group C, west of the road and uphill from Group A. Groups A, B, and C are located south of town, between it and the bridge of Tamazulapa. All appear to be more or less of the Late Classic Period, in part contemporaneous with the Acropolis at Copan. These groups consist mainly of small courts each dominated by a larger structure. All constructions, of mud and slate on lava-block foundations, are oriented roughly to the cardinal points. Another type of construction seen in these groups is the tombs, of which there seem to be a great many, both sacked and untouched. All are vaulted.

Group D is located about 1 km. due north of town. It consists of a number of round, much eroded mounds, irregularly placed, built of mud with very little admixture of river boulders and no slate. Wherever a road cut through a mound, potsherds were gathered. These proved to be of Usulután ware and decoration, very similar to ceramics of the Miraflores phase in the Guatemala highlands. No polychrome pottery was recovered at Group D.

There apparently was a pre-Columbian settlement just where the town of Asunción Mita is now located. We were told by inhabitants that wherever one digs, artifacts turn up. A typical stone "yoke" and some pottery showing accentuated phallic symbols have been found here. Mexican affinity is suggested, and one wonders if the remains may be Pipil.

In reviewing the findings at Asunción Mita and vicinity, we seem to see three phases of occupation: (1) A population of Mexican stock apparently resided here at the time of the Spanish conquest, how long is unknown. (2) There was a Classic Maya phase of unknown duration, contemporaneous with one phase at Copan, when Copador pottery spread over parts of Honduras and El Salvador. That was the high point in the Maya culture. (3) There apparently also had existed an earlier settlement, characterized by earth mounds and Usulután pottery, and probably contemporaneous with the Miraflores phase in the Guatemala highlands.

CAMPECHE

GEORGE W. BRAINERD

The purpose of the field work undertaken in Campeche this year was the linking of the ceramic sequences of Yucatán and the Petén region of Guatemala by excavation at a series of intermediate points in the area lying between them. The work was in charge of Dr. George W. Brainerd, who took six months' leave of absence from the University of California at Los Angeles and from the Southwest Museum for this purpose. Mr. Karl Ruppert, who was thoroughly familiar with the southern part of the area to be worked, was the other member of the expedition.

Previous architectural exploration of this intermediate territory between the northern and central Maya ruin areas had been done by Ruppert (*Archaeological reconnaissance in Campeche, Quintana Roo, and Petén*, Carnegie Inst. Wash. Pub. 543), and by Dr. H. E. D. Pollock (Year Book No. 35, 1935-1936, pp. 122-125). The standing ruins in the Chenes, which is the northern part of this area, are distinctive and are similar in many particulars of style to those of the southern part of the area,

which has been called Rio Bec after the site of that name. These two architectural styles (or, perhaps better, this joint style) are in turn easily distinguishable from that to the north in the adjoining Puuc area of Yucatan, and from that of the central or Peten Maya area which adjoins the Rio Bec area to the south. The explored Chenes and Rio Bec sites are separated by about 100 km. of unexplored area which presumably also contains ruins of Chenes-Rio Bec architectural style.

Three sites were tested ceramically this season: Santa Rosa Xtampak and Dzibilnocac in the Chenes region, Xpuhil in the Rio Bec area. Collections were also made at other sites within 30 km. of Xpuhil. Approximately three months were spent in excavation. The next three months were spent in Merida in recording the collections, to be followed by a month at Los Angeles in analysis and preparation of a report. During the time in Merida Mr. R. E. Smith gave two weeks to the identification of Peten influence and trade in the collections. This procedure was of great benefit in establishing approximate chronological equivalence between the Campeche ceramics and the sequence at Uaxactun in the Peten, where stratigraphic phases have been fixed in time by Maya dates on accompanying monuments.

The determination of the correct time relations between the ruins of the Peten and Yucatan areas is of importance both in the telling of Maya history and in the dating of the Maya culture in terms of the Christian calendar. The Chenes-Rio Bec area, intermediate between the two, is the likeliest place to look for datable connections between them. Its study is also important in the determination of the nature and direction of cultural influence at all periods between Yucatan and Peten.

All three sites dug showed evidence of occupation ranging from pre-stela (Forma-

tive) times until somewhat before the period of Toltec influence at Chichen Itza. In each site, however, one period predominated in the pottery, presumably that of the standing architecture of the site. This period in all cases was characterized by a predominance of the Medium Paste Slateware which also predominates in the Puuc ruins and others of the Classic Period in Yucatan. The occurrence of this pottery at Xtampak in quantity in the terrace underlying stelae, two of which bear Maya dates of approximately 9.16.0.0.0, gives a contemporaneous date for this ceramic horizon in the Maya calendar. This dating by sherd material was reinforced by the finding of cache pottery of Classic ware in the stela platform. The terminal dates of the period are harder to work out, but some information should appear from the detailed analysis not yet begun. At present there is a suggestion that the occupation of the Puuc sites was somewhat later than, though overlapping in time with, that of the Chenes sites. The beginning date of this pottery period is also not closely fixed as yet. The absence in all three sites of clearly defined deposits between the Classic and the underlying Formative suggests either a period of abandonment or a longer use of the pottery we call Classic. At various sites in Yucatan a series of ceramic phases between Formative and Classic have been found and designated by the general term Developmental. Yucatan Developmental pottery occurs very sparingly in the Chenes sites tested.

Dating in the Maya calendar of Chenes architecture at Xtampak is given confirmatory evidence by Smith's classification of the Peten tradewares. The majority of polychrome tradeware sherds from each site tested falls into the Uaxactun subphase Tepeu 2, which Smith dates 9.13.0.0.0-9.19.0.0.0. Thus the dating of the Chenes and Rio Bec architectural styles falls well

within the Maya Initial Series Period. The coming detailed analysis of these collections should limit more closely the dating of the Yucatan periods in reference to the period of these sites.

The degree of cultural similarity among the material of the Puuc, Chenes, Rio Bec, and Peten areas is useful in evaluating Maya cultural development. Both Chenes and Rio Bec pottery of the Classic Period show preponderant percentages of Medium Paste Slateware, the chief Yucatan ware of this period. This ware is distinctive from that of the Peten. The pottery of each of these three Slateware areas, however, is easily distinguishable from that of the others by differences in detail of vessel forms. The finer monochromes of the Rio Bec area are very similar to certain wares of their corresponding horizons in the Peten, whereas the Chenes fine monochromes resemble those of the Puuc area. These degrees of relationship seem at least roughly to parallel the architectural relationships which have been observed.

An additional finding of interest is that of a new Formative phase which seems to precede the Late Formative apparent in nearly all Yucatan sites thus far sampled. The Yucatan Late Formative, as well as that found in the Campeche sites this year, bears certain marked similarities to types of pottery found in the Chicanel phase at Uaxactun, according to the findings of R. E. Smith. There are also sporadic resemblances to the earlier Mamom Uaxactun phase. At Dzibilnocac and Xtampak were found deposits of a phase seemingly earlier than Late Formative and showing ware and form resemblances to the early deposit found at Mani under a late Formative deposit (see Year Book No. 41, 1941-1942, p. 255). At Dzibilnocac the deposit of this new phase includes some Late Formative pottery; at Xtampak the diagnostic Late Formative wares are absent.

This period may be provisionally called Middle Formative; the Mani deposits, Early Formative. The Middle Formative phase shows less similarity to Chicanel than does the Late, but no similarity to Mamom. The Early Formative seems to show no resemblances to any pottery of other areas thus far known.

The dating of the Early and Middle Formative periods of the northern Maya area is not at present a profitable subject even for conjecture. The Middle Formative collections are small; the Early Formative, although larger, are limited almost exclusively to water jars. The distinctive character of these periods is striking, but further excavation is imperative before they can be properly placed. The study of the cultures sampled this season has scarcely been initiated.

CERAMIC TECHNOLOGY

ANNA O. SHEPARD

Work in ceramic technology has been concentrated on two principal projects during the current year: the preparation of a general book on ceramics for archaeologists, and a special study in the Southwestern field. The purpose and plan of the ceramics book has been stated in an earlier report (Year Book No. 46, 1946-1947, p. 190). The Southwestern study, also mentioned previously (Year Book No. 47, pp. 219-220), deals with the brown wares of the southern part of the area, the so-called Mogollon pottery.

The age and the place in Southwestern culture history of the Mogollon people has been a central theme of controversy among archaeologists for a number of years. One school has maintained that the Mogollon constitutes a distinct basic culture which influenced the better-known Pueblo development to the north; the other school regards the Mogollon as merely a variant

Pueblo culture. This question of basic cultures is one of definition and does not directly concern the technologist, whereas the record of contacts between peoples and their interactions is one of primary interest to him because it is preserved in no small measure by pottery. Furthermore, the interpretation of ceramic characteristics is one of his direct concerns and responsibilities. Brown pottery is an important diagnostic of the southern culture, and the contrast of its color with that of Pueblo pottery in the north, which is whitish or gray, is generally considered indicative of a fundamental difference in preferences and practices of the Mogollon potters. Quite aside from the question of how much weight should be given pottery color in evaluating a culture, there is need of reviewing the factors which affect the color of fired clay. Composition of clay and method of firing, or, stated in other terms, natural resources and a trait of material culture, are both primary factors. Stressing the latter to the neglect of the former leads to erroneous conclusions. If the same kinds of clay had been available throughout the Southwest, the color difference in the pottery of the two regions would reflect the potters' choice of clay and method of firing and could be considered an independent culture trait. But this is not the case. In much of the northern part of the territory there are extensive formations of Cretaceous age which abound in good-quality, buff-firing clay. These formations are absent throughout most of the southern part of the area, where the common clays are red-firing. To overlook this fact magnifies cultural differences. Likewise the idea that brown wares are earlier and more primitive than grays and that similarity of color indicates relationship arises from failure to recognize that the most widely distributed and abundant clays are red-firing. The Pueblos

of the north were favored in their ceramic resources and in consequence developed a nearly unique class of primitive pottery.

Evidences of contact between Mogollon and Pueblo peoples consist largely in trade pottery: black-on-white in southern sites, and red, brown, and smudged in northern. The latter have been identified as Mogollon only by surface appearance. One of the purposes of the Southwestern technological project has been to determine as far as possible the source of all supposed Mogollon intrusives and to consider the bearing of technological features on the question of the influences of the two peoples on each other. It has been necessary first to define the range of paste variations in the Mogollon area as far as collection and survey permit. This work has in itself direct archaeological applications. Since the two principal types of Mogollon pottery, red and brown, are undecorated and lack distinct, variable features of workmanship, varieties peculiar to certain localities or period, cannot be recognized by simple inspection, and consequently pottery does not serve as fully as in some areas to correlate occupations and to establish time sequences. This is a serious disadvantage, because the pottery was made over a large area and during a considerable time span. If it is to be broken down into spatial and temporal varieties, this must be done primarily on the basis of body composition. Pottery from the Petrified Forest region illustrates how paste analysis may add detail to the picture and alter interpretations. Sherds from twenty-one sites surveyed by the Laboratory of Anthropology included a brown ware defined as a homogeneous type which upon petrographic analysis was found to include four different pastes identified by temper. Of the four tempers—sand, sherd, altered feldspar, and volcanic rock—the last named occurred in only one specimen, which was

doubtless an intrusive from the south. The principal pastes, sand- and sherd-tempered, show sufficient difference in distribution to suggest that they were made by different peoples or at slightly different times, a possibility considered by the Museum of Northern Arizona in selecting sites for excavation in the region this summer. A clear-cut and readily recognized temporal difference in paste occurs in the Forestdale region, where most of the pottery is sand-tempered, but an early variety from Bluff Ruin is tempered with crushed diabase.

Collections studied to date, in addition to those mentioned, are from Dr. Emil Haury's excavation at Point of Pines, Dr. Paul Martin's from the SU site, the major excavated sites of the Mimbres region, and San Simon to the southwest. Collections from some sixty sites covered by Peabody Museum's survey of the north central and northeastern part of the area are now in process of analysis.

The project has been a venture in co-operation, since we have depended for pottery on a half-dozen institutions, and many of the archaeologists representing them hold sharply opposed views. Both samples and data on provenience and frequency of occurrence have in every case been supplied freely and generously, and there has been no reluctance to loan even rare sherds. The study has also been greatly facilitated by a gift of 333 analyzed petrographic sections from Mr. Harold Gladwin, of Gila Pueblo, and Mrs. Nora Gladwin Fairbanks. The collection was prepared and studied by Mrs. Fairbanks for Gila Pueblo and includes a large series from Mogollon sites.

A short study of Mesa Verde pottery from the excavations of Dr. Deric O'Bryan was undertaken because of its close similarities to La Plata pottery analyzed for Dr. Morris some years ago. The study clarified the relationship of pottery types

and showed distinct fluctuations in classes of paste which, when correlated with other archaeological data, may have a bearing on the shifts of peoples within the region. One interesting result was the discovery that a considerable proportion of the pottery, including nearly all the earliest, was tempered with crushed andesite, a source of which was found in an early gravel sheet on the Mesa. That Basket Maker III potters should search out this deposit and select from it the igneous rock would indicate that they came to the Mesa from a region, such as the La Plata Valley, where it was the custom to temper with crushed rock instead of sand, the common temper of this period.

LINGUISTIC RESEARCH

NORMAN A. McQUOWN

Dr. McQuown's primary purpose in his trip to Guatemala in the summer and autumn of 1948 was to educate himself with respect to the phonemics and a good part of the morphology and syntax of the Mam language. Among his secondary purposes were: to familiarize himself with the phonemics of the other Guatemalan languages in which Andrade made phonograph recordings (Quiche, Kanjobal, Quekchi); to do the phonemics of Cakchiquel, for which Andrade gathered extensive written texts (transcribed by Juan Rosales); to take a look at Xinca, in order to get an outside check on Maya-non-Maya cultural contacts; and to make arrangements (both in Guatemala and in Mexico) for utilizing, so far as possible, the Maya materials already collected, or in process of being collected, by missionaries working with these languages in the field, and to ensure their collaboration and aid in further work on the languages of the family. A certain measure of success was attained in all these undertakings.

Five months were spent in Guatemala and Mexico, and the items listed were accomplished:

(1) Three and a half months were spent in Guatemala City, working on Mam, with an informant generously furnished by the Instituto Indigenista; and one week was spent with Mr. and Mrs. H. D. Peck, at Txol Be, San Juan Ostuncalco. (a) A Mam grammar and dictionary file of some 7500 entries was accumulated. (b) The phonemics and a considerable portion of the grammar of Mam was worked out. (c) Some ten Mam texts were collected incidentally, in the process of teaching the informant to write with a phonemic alphabet. (d) The Instituto Indigenista was provided with a Mam alphabet. (e) Mutual orientation sessions were held with the Pecks, in which the problems of Mam phonemics and grammar were discussed. (f) Arrangements were made with the Pecks, with the informant, and indirectly with Mr. and Mrs. Edward Sywulka, to collaborate in the preparation of a Mam dictionary. (g) Arrangements were made with the Pecks to complete the transcription and translation of Andrade's 300 Mam recordings (all material to be phonemically transcribed according to a system worked out on this trip); they have already made great progress, and should be able to complete the work in another year. (h) Arrangements have been made with Mr. Edward Sywulka to have access to his master's dissertation, "A morphology of the Mam language," recently completed at the University of Oklahoma. The continued collaboration of Mr. Sywulka and of the Pecks in working out unsolved problems of Mam grammar will probably make further actual field work on Dr. McQuown's part unnecessary for completing the descriptive phase of the work on Mam.

(2) Two weeks were spent in becoming familiar with the phonemics of the Quiche,

Kanjobal (Jacalteco), and Quekchi languages, in each of which Andrade made a fair number of recordings (55, 37, and 23, respectively). (a) Two days were spent in Chichicastenango, working on Quiche, with three informants from Chichicastenango and one from Totonicapán. A vocabulary of 1000 items was taken and a tentative sketch of the phonemics was worked out (subsequent work in the Instituto Indigenista with another informant from Totonicapán verified the results of the first sketch and, in addition, established beyond question the phonemic status of the short and long vowels). Brief checking was done on a preliminary transcription of the Quiche recorded materials prepared by Andrade (the newly discovered feature of vowel length will make retranscription of all materials necessary). The Instituto Indigenista was provided with a Quiche alphabet; on the previous trip to visit the Pecks, arrangements were also made with Mr. and Mrs. Stanley Wick, working with the Quiche of San Cristóbal, for future collaboration in all aspects of the work on Quiche. (b) Two days were spent in Huehuetenango, working on Kanjobal (Andrade's Jacalteco) of Santa Eulalia, with the informant of Mr. and Mrs. Newberry Cox, at present in San Miguel Acatán. A vocabulary of some 1500 items, a text, and some paradigmatic materials were recorded; a tentative sketch of the phonemics was worked out; vowel length was not found, but subsequent work with other Guatemalan Maya languages (Quiche, Cakchiquel, and Quekchi) which have it makes a recheck desirable (although there is evidence that some of the Chiapas languages do not have phonemic vowel length and that Kanjobal may belong with them rather than with the other languages in Guatemala). The collaboration of the Coxes will make this recheck possible without further field

work; they can also be counted on for help in the transcription and translation of that part of Andrade's recorded material which is as yet unworked. The Instituto Indigenista was provided with a Kanjobal alphabet. (c) Two days were spent in San Juan Chamelco, working on Quekchi, with the informant of Mr. and Mrs. William Sedat. A vocabulary of some 1000 items was recorded; a tentative sketch of the phonemics was worked out (phonemic vowel length was definitely established). The collaboration of the Sedats can be counted on in the future, for the working out of the grammar, and the transcription and translation of that part of Andrade's materials which is as yet unworked. The rechecking of the already transcribed materials will in the case of the Quekchi involve a minimum of effort, since Andrade indicated in these materials a fair portion of the long vowels. The Instituto Indigenista was provided with a Quekchi alphabet.

(3) One week was spent on the phonemics of Cakchiquel; one day was spent in San Pedro Yepocapa, working on the local dialect. A vocabulary of some 750 items was recorded, and a beginning was made toward teaching the informant to write; a tentative phonemic sketch was worked out. Subsequently, three days were spent in Panajachel, working on a slightly divergent dialect, with five informants. A vocabulary of some 1300 items was recorded; a tentative phonemic sketch was worked out (subsequent work in the Instituto Indigenista with an informant from Comalapa, and in Mexico with Juan Rosales of Panajachel, confirmed the sketch, and established both short and long vowels as phonemic)⁴. The Instituto Indigenista was provided with a Cakchiquel alphabet. Juan Rosales, in view of the establishment of vowel length as phonemic, will have to recheck the texts

written by him, indicating long vowels where they occur.

(4) The extra-familial check was accomplished in two days, which were spent in Chiquimulilla, working on Xinca, with an informant from Santiago and one from San Sebastian. A vocabulary of some 750 items was recorded and a tentative sketch of the phonemics was worked out. The Instituto Indigenista was provided with a Xinca alphabet. Subsequent inspection of the Xinca vocabulary showed some dozen loan words, some from Nahuatl languages, some from Maya; consideration of the Maya loans ("bean," "mat," "custard apple," "witch doctor," "ladino") shows that they were borrowed from Mam or from Kanjobal (or from one of the Chiapas languages), indicating a previous more northerly location for the Xinca; comparison of "bean" (from Maya) with "corn" (either a loan from Lenca or a loan into both Xinca and Lenca from a third language) would indicate that "bean" was acquired considerably later than "corn," and was introduced to the Xinca (and apparently to the Lenca and other Middle American groups) by the Maya. These "explanations" are only conjectures, of course, but they indicate how extremely fruitful further work might be. Xinca is rapidly going out; someone should do a thorough study before it becomes extinct.

(5) The fifth purpose was accomplished, by and large, in the personal meetings with individual missionaries. Collaboration has been secured with the Pecks and the Sywulkas for Mam; with the Coxes for Kanjobal; with the Wicks for Quiche; with the Oughtens for Ixil; with the Sedats for Quekchi; with Antonio Goubaud and the workers of the Instituto Indigenista for Cakchiquel, Quiche, and Mam; with the workers of the Summer Institute of Linguistics in Mexico for all the Maya languages there. In Mexico, ma-

terials for volume 26 of the University of Chicago's Microfilm Series on Middle American Cultural Anthropology (texts and dictionaries in Chol, Tojolabal, and Tzotzil) were obtained from the Summer Institute and were filmed; other Maya language materials of Summer Institute workers will be added to this series from time to time.

HISTORY OF THE MAYA AREA

RALPH L. ROYS

During the past year *The prophecies of the Maya tuns or years in the Books of Chilam Balam of Tizimin and Mani* has been completed for publication, and some time has been spent in reading the proofs of this Contribution and the *Guide to the Codex Perez*.

The source material for the history of Mayapan has been assembled and translated into English from the Spanish and Maya, where such translations were not already available. The sources quoted are accompanied by commentaries, in which they are compared and discussed and some of the more important implications are noted.

There is fairly good evidence that the area ruled by Mayapan included most of the Yucatan Peninsula north of Campeche, although the evidence for the northeast and east coasts is conflicting. Nothing has been found about Campeche in this connection.

Taken as a whole, the references to Mayapan indicate the need of a new interpretation of the source material. In the past, historical reconstructions have been based principally on the chronology of the Maya Chronicles in the Books of Chilam Balam, but with unsatisfactory results. Uxmal, Chichen Itza, and Mayapan were long considered to have been contemporary capitals in Yucatan, but archaeol-

ogists have found that their more important building activities occurred at three different periods in the order named. J. E. S. Thompson has noted the weakness of this chronology, and a comparison of all the historical sources suggests that the accounts by Gaspar Antonio Chi offer a framework in which Landa's narrative and the episodes related in the Chronicles could more easily be reconciled with the archaeological findings. This compilation also presents evidence that the important Xiu family became a political factor in northern Yucatan only in the late fourteenth or early fifteenth century, and not in the eleventh century as previously believed.

The late winter and spring were spent in Yucatan continuing previous studies of the political geography at the time of the Spanish conquest (Year Book No. 36, 1936-1937, pp. 23-24; No. 38, 1938-1939, pp. 252-253). One purpose of the present survey was to see what indications exist that the modern towns are situated at conquest sites of the same names; another was to locate historic sites that are no longer shown on the maps.

A search was also made for conquest sites which would be likely sources for the recovery of late preconquest and early colonial pottery. Although ceramic sequences have been established from very early times down to the fall of Mayapan, about the middle of the fifteenth century, it has been difficult to find sherds which could be identified as belonging to the period following that time. It seems possible that this is partly due to a Spanish policy of replanning the Indian towns, by which it is known that the houses were concentrated nearer the church and central plaza and for the first time arranged along regular streets with smaller yards and gardens than previously. Several centuries of occupation in colonial and modern times

have further aggravated this disturbance of the topsoil containing the sherds which had accumulated during the last pre-Spanish period and that of the conquest. For this reason particular attention was paid to historic sites from which the people had been removed at a fairly early period. A few of these—Hunacti, Calotmul, and Cauich—had been located during previous visits to Yucatan. This year four more were visited and identified: Kanchunup near Sotuta, Tecoh near Izamal, Tuchiaan near Maxcanu, and Quizil near Uman. Hunacti and Kanchunup were subject to European influence for the shortest time, since they were left deserted prior to 1582, and very possibly as early as the 1560's. The churches of these two towns, as well as at Tecoh and Quizil, were of an early type. Only the chancel, sacristy, and priests' quarters were built of masonry. There was no nave, and the congregation evidently occupied an open structure of pole and thatch, called a *ramada*, of the sort described in various sixteenth-century Spanish reports. It seems probable that all four sites were abandoned at an early date. Since there are cenotes at three of them and a pond of potable water at Tecoh, they would appear to be promising sources of late preconquest and early colonial pottery. Tuchiaan and Tecoh are of especial interest, since both played an important part during the Spanish invasion of Yucatan. There are still extensive Maya ruins at all seven sites mentioned above except Kanchunup and Cauich.

Indications exist that a very large number of the colonial churches in Yucatan were built partly of hewn blocks taken from ancient structures in the immediate vicinity, although such material apparently was sometimes supplemented, as at Kinchil and Kaua, by hewn stone from other sites as far as 6 km. distant. Two of the oldest convents, at Merida and Izamal, were

built on the summits of fairly high substructures, and in the northwestern and the northern parts of the state, as far east as the vicinity of Izamal, a great many churches are set in spacious patios which are raised from 1 to 2 m. above the level of the town. In such cases this platform appears to have been constructed from the rubble fill of a large Maya substructure. Possibly it consisted partly of the flattened base of a pyramid and was completed from other neighboring mounds. There is some evidence of this at Hunucma and still more at Chuburna. Raised platforms on which the churches stand are much rarer in the Sotuta and Valladolid areas farther east, and in the former Xiu Province of Mani to the south.

These raised church patios are frequently enormous structures, although they probably average only about 1.5 m. in height. Roughly paced off, those at Hunucma, Kinchil, Hocaba, and Humun have an average surface of about 8000 sq. m. The platform at Humun is 3 or 4 m. in height, but here it is partly formed of a low rocky knoll. Nowhere did there appear to be a depression from which this material might have been excavated. There are still many large Maya ruins in northern and northwestern Yucatan, but this use of the substructures for church platforms probably explains why they are not so numerous today as would appear from the sixteenth-century Spanish reports. In spite of the important fisheries and salt industry in former times, agricultural conditions in northwestern Yucatan are such that it is difficult to explain the great building activities which evidently existed. Apparently there was a highly developed social organization over a very long period of time, and in this connection it seems relevant to note that some sherds gathered at Candel, when submitted to Dr. G. W. Brainerd, were identified as corresponding

in age to the Chicanel phase at Uaxactun.

In a number of towns, where the site of the church is raised but little or not at all above the surrounding area, some of the old pyramids or other substructures were left standing in the immediate vicinity. This has been recorded of the cathedral at Merida and the church at Motul. It is still the case at Ucu and Caucel, both of which might be considered sites of some promise for recovering sherds of the conquest period. Other instances can be cited at Yaxkukul, Acanceh, Sotuta, Dzán, Chapab, and Teabo. At Sotuta a large substructure near the church is surmounted by a fortified colonial building. Similar remains are also to be seen at Chicxulub, Ticul, Oxkutzcab, and near Tekax, but, like many others reported from Yucatan towns, they lie at some distance from the church and the center of town.

Visits were made to the ruins at Ake, Acanceh, Izamal, Uxmal, Chichen Itza, and Mayapan, and to the town of Champoton, all of which figure in the historical legends of the Books of Chilam Balam. At the time of the Spanish conquest Champoton was a large and commercially important town with many stone buildings. Although the architectural remains are scanty, there are still a number of scattered drums of cylindrical columns. They are rather roughly hewn and are reminiscent of those at Mayapan. Surface sherds are abundant in the streets, and the gullies which intersect the town seem to offer some promise of stratified deposits.

HISTORY OF SCIENCE

GEORGE SARTON

As my connection with Carnegie Institution ends August 31, 1949, it seems proper to devote this, my final, report not only to the last year but to the whole duration of my service, which began July 1, 1918.

Rereading my yearly reports, the first of which appeared in Year Book No. 18 (1918-1919), I find that my main work was not announced until the third report (Year Book No. 20) and that I began the writing of my *Introduction to the history of science* only on January 12, 1921. When I started that undertaking, I did not, and could not, realize its size, complexity, and difficulties; I thought that it would occupy only part of my time and that I would be able to complete two other projects, each of which was of lifetime size. These two projects were, first, a history of modern physics (physics in all its ramifications in the nineteenth and twentieth centuries); second, a full account of the life and achievements of Leonardo da Vinci.

As this second project is not unrelated to the main undertaking, I may be permitted to say a few words about it. In 1916, I had delivered six lectures on Leonardo da Vinci at the Lowell Institute in Boston. After the completion of that course of lectures it dawned upon me that my knowledge of the subject was very insufficient. Leonardo, sometimes called the father of modern science, was the child of the Middle Ages. In order to appreciate his thoughts correctly it was necessary to have a deeper knowledge of medieval science than I could boast at that time. It was probably then that I resolved to make a systematic and thorough survey of the progress of science, century by century; I sincerely thought that I would be able to reach our time, or at least the beginning of this century, within ten or twenty years. In reality, so many were the obstacles that I did not even reach Leonardo's time, but had to stop my survey about the year 1400.

The main cause of delay was the necessity, unsuspected at first, of studying the Arabic language. This was a heavy task in itself. At first, I had been helped by my kind friend the Rev. Duncan Black

Macdonald (1863-1943), of Hartford, Connecticut, but in spite of his willingness he was not always able to help me, nor could I appeal to him as often as would have been necessary, and the obligation to study Arabic could not be eschewed any longer.

It is proved in great detail in my *Introduction* that for three centuries at least (the ninth to the eleventh), Arabic was the international language of science, and that in the following two centuries (the twelfth and thirteenth) the study of it remained the shortest cut to up-to-date knowledge. We often speak of the iron curtain separating eastern from western Europe; another curtain began to separate them (that is, to separate the Orthodox, Greek East from the Latin, Catholic West) as early as the fifth century, and three centuries later it had become almost impenetrable. The Latin doctors refused to read Greek; therefore, they were finally obliged to read Arabic, a language entirely unrelated to theirs, the language not of Christians but of Muslims. That is one of the paradoxes of history. It is because of it that medieval science and medieval culture cannot be understood without a sufficient knowledge of the Arabic writings.

While I was engaged in the survey of ancient and medieval science which would bring me back within a few years (so I thought) to Leonardo, the Carnegie Institution commissioned Professor J. Playfair McMurrich (1859-1939), of Toronto, to investigate Leonardo's anatomical drawings and notes. Indeed, it is clear that Leonardo's main source in this field could not be medieval knowledge, but only his own dissections, and the value of his anatomical drawings could not be appreciated except by a man with a long anatomical experience. The results of Professor McMurrich's investigations were published by the Institution in 1930 (J. Playfair McMurrich,

Leonardo da Vinci the anatomist (1452-1519). Carnegie Inst. Wash. Pub. 411. xx+265 pp., frontispiece, 89 figs. *Isis*, vol. 15, pp. 342-344).

In the meanwhile, volume 1 of the *Introduction to the history of science*, dealing with the period from Homer to Omar Khayyam, a period of two thousand years, had appeared in 1927, and volume 2, in two parts, devoted to the twelfth and thirteenth centuries, appeared in 1931. The effort made to bring these volumes to relative perfection had been so long-drawn and intense that it left the author exhausted. Thanks to the wisdom and generosity of the Institution, I was permitted to spend a sabbatical year abroad. I resided half a year in Syria, where I was a guest of the American University of Beirut and was able to extend my knowledge of the Arabic language, the Arabic people, Eastern Christianity, and Islam. Shorter times were spent in other countries which were (or had been) parts of the Arabic or Islamic world: Egypt, Palestine, Turkey, Rhodes, Cyprus, Tunis, Algeria, Morocco, Spain, and Sicily. After my return to Cambridge my work was resumed and centered upon the fourteenth century. This again took far more time than had been expected—volume 3 (in two parts) appeared only in 1948—partly because my standards of scholarship had become more severe as my experience increased, partly because the amount of accumulated materials was so much greater. Materials had been accumulating for the whole work from the beginning; the accumulation had lasted about 9 years for volume 1, 13 years for volume 2, 27 years for volume 3. Many of the documents had been published, or at least listed, in *Isis*. By the time of publication of volume 1, 27 numbers (almost 8 volumes) of *Isis* had appeared, including 18 critical bibliographies; by the time of publication of volume 2, 46 numbers (al-

most 15 volumes), including 30 bibliographies; by the time of publication of volume 3, 103 numbers (35 volumes), including 67 bibliographies, plus 7 volumes of *Osiris*. The materials contained in the *Introduction*, *Isis*, and *Osiris* are integrated by means of thousands of cross references. Thus we may say that volume 1 was built on a foundation of 8 volumes; volume 2, on a foundation of 15; volume 3, on a foundation of 42.

Reference to *Isis* suggests that the mass of information included in the three published volumes of the *Introduction* is much larger than appears at the surface. These three volumes include 4334 pages, but there is scarcely a page which does not refer to *Isis* or *Osiris*, where more information can be obtained immediately. Moreover, additions and corrections to the published volumes are included periodically in the critical bibliographies of *Isis*, the 75th of which is now in process of preparation, to appear in volume 41.

The author is keenly aware of the need of correction and amplification, but such as it is, the *Introduction* is the most elaborate work of its kind, and by far, in world literature. This statement can be made without falling under the suspicion of boasting, for it is objective, controllable, and obviously correct.

At the end of my thirty years of service, I wish to express my deep gratitude to the Institution which made it possible for me to do the work which I loved best and for which I was most fit. Thanks to its patronage, Rooms 185 and 189 of the Widener Library, Harvard University, became an international center and clearing house for the history of science. These rooms were never called an "institute," but they deserved the name far more than many of the "institutes" attached to European universities.

It is certain that every student of the

history of science, the world over, shares my gratefulness to the Carnegie Institution for having allowed this fundamental work to be undertaken and partly completed. The history of science is like any other discipline in the field of science or the humanities, in that the fundamental work is slow and difficult, and the results austere. It is also expensive, or at least seems to be. It requires the most expensive of all scientific instruments, far more expensive than the greatest telescopes or cyclotrons—a large library, the larger the better (try to evaluate the total cost of such libraries as the Library of Congress or the Harvard College Library). To this one may answer that though the historian of science needs such a library more than any other scholar, he is not by any means alone in using it. Each library is used simultaneously by many thousands of people. In the second place, genuine scientific work is always expensive, at any rate as compared with secondhand work which requires only enough literary ability to exploit the investigations of other people or rephrase their reports; scientific work is apparently expensive, but it alone has any chance of permanence. The popular books, however successful (and their success is often in inverse ratio to their scientific value), are ephemeral; one can never really depend upon them; it is hardly worth while to refer to them. The writing of such books is a Sisyphean labor without value, except perhaps a monetary one. It must be done over and over again. There is no cheapness in them, at least no financial cheapness. For a longer explanation of my views than there is space for here, the reader is referred to my article "The scientific basis of the history of science," published by the Institution in the volume dedicated to the late President Merriam, *Cooperation in Research* (Carnegie Inst. Wash. Pub. 501, pp. 465-471, 1938).

PUBLICATIONS

MARGARET W. HARRISON

Volume X of Contributions to American Anthropology and History (Publication 585), now in page proof, contains four papers: *The Maya Chronicles* (no. 48), by Alfredo Barrera Vasquez and Sylvanus G. Morley; *Guide to the Codex Perez* (no. 49), by Ralph L. Roys; *The Pendleton ruin, Hidalgo County, New Mexico* (no. 50), by A. V. Kidder and H. S. and C. B. Cosgrove; and *The prophecies for the Maya tuns or years in the Books of Chilam Balam of Tizimin and Mani* (no. 51), by Ralph L. Roys. This group completes the volume, which will be issued in the fall of 1949.

The Maya Chontal Indians of Acalan-Tixchel: a contribution to the history and ethnography of the Yucatan Peninsula (Publication 560), under the joint authorship of France V. Scholes, Vice-President of the University of New Mexico, and Ralph L. Roys, with the assistance of Robert S. Chamberlain and Eleanor B. Adams, was published early in the winter of 1949.

A. Ledyard Smith has completed his part of the general survey of the Division's work at Uaxactun. His monograph, entitled *Uaxactun, Guatemala: excavations of 1931-1937* (Publication 588), is now in press; it will be followed shortly by Robert

E. Smith's companion report on the pottery at this site. Dr. Kidder's introduction to the first book gives the archaeological background for both studies.

J. Eric S. Thompson's *Maya hieroglyphic writing: introduction* (Publication 589) is in galley proof. It forms the first volume of Mr. Thompson's projected series on this subject and will be published by the end of 1949.

Two compilations were mimeographed and issued by the Division this year: *Historical source material for the history of Mayapan*, by Ralph L. Roys; and *Selected references on the Maya area*, brought up to date as of December 1948, by Margaret W. Harrison.

The fourth volume of Notes on Middle American Archaeology and Ethnology was begun with three papers: the first two by Dr. Kidder, listed in the bibliography following this report; the third, *Some new discoveries at Coba* (no. 93), by William R. and Michael D. Coe.

Several manuscripts soon to be presented by the Division for publication await completion of editorial work: *The conquest of Honduras and Higuera*, by Robert S. Chamberlain; *Copan ceramics: a study of southeastern Maya pottery*, by John M. Longyear III, of Colgate University; and *A study of Classic Maya sculpture*, by Tatiana Proskouriakoff.

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SPECIAL PROJECTS: HISTORICAL RESEARCH

E. A. LOWE, The Institute for Advanced Study, Princeton, New Jersey. *Collection and study of paleographical material*. (For previous reports see Year Books Nos. 9 to 35, 37 to 40, and 47.)

The four volumes of *Codices latini antiquiores* so far published have dealt with the oldest Latin manuscripts in the Vatican City, in Great Britain and Ireland, and in Italy outside the Vatican City. The next two volumes deal with the manuscripts preserved in France: volume V deals with the Paris manuscripts, volume VI with the manuscripts in French libraries outside of Paris. The Paris manuscripts are nearly all in the Bibliothèque Nationale; a few are in the Arsenal and Ste Geneviève libraries, and some papyri are in the Louvre. Together they comprise a round two hundred items, making volume V almost twice the size of volume I. The fifth volume is nearly all set up in type. The lay-

out of the facsimiles was completed last October, and work on the collotypes is to begin shortly. Barring unforeseen obstacles, the volume may see the light by the end of 1949. One hurdle, however, still remains to be cleared: the papyri in the Louvre Museum have so far been inaccessible. It is greatly to be hoped that it will soon be possible to photograph them.

Field work on volume VI has commenced. Preparations are now being made for taking the necessary photographs of items scattered in a rather large number of libraries. It is gratifying to report that the editor can count on the helpful co-operation of the French libraries.

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